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Automation and Robotics

Communications Systems

Computer Sciences

Controls and Guidance-Aeronautics

Controls and Guidance-Space

Data Systems

NASA Technical Memorandum 4064

NASA Information Sciences and Human Factors Program

Annual Report, 1987

JULY 1988

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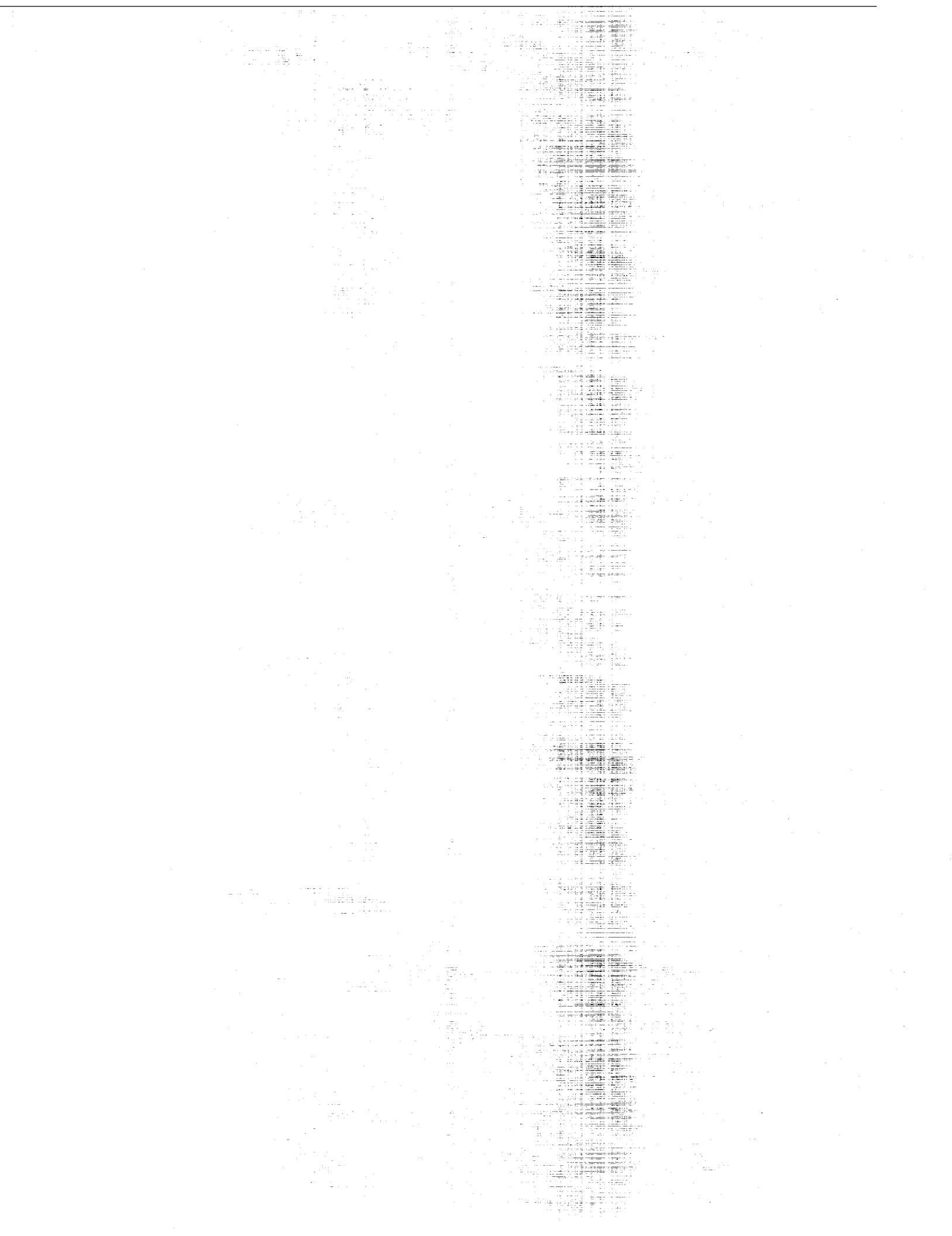

NASA Technical Memorandum 4064

NASA Information Sciences and Human Factors Program

Annual Report, 1987

NASA Office of Aeronautics and
Space Technology

Information Sciences and Human
Factors Division

National Aeronautics
and Space Administration

**Scientific and Technical
Information Division**

1988

INTRODUCTION

The Information Sciences and Human Factors (IS&HF) Division is one of the five divisions that comprise NASA's Office of Aeronautics and Space Technology (OAST). This division sponsors research in both aeronautical and space technology. This Annual Report documents the most significant accomplishments during the past year. Each year, the Annual Report is prepared to serve as the primary mechanism for coordinating NASA activities with industry and industrial IR&D managers. This document is also intended to communicate significant technical accomplishments to NASA technologists, project engineers, other government agencies and academia.

The IS&HF Program consists of seven major elements: Automation and Robotics, Computer Sciences, Communications, Controls and Guidance, Data Systems, Human Factors, and Sensor Technology. Accomplishments are presented in all seven categories: Controls and Guidance and Human Factors are shown in two sections, Space and Aeronautics. Total program funding, including civil service manpower costs, for FY88 is shown below.

Element	Aero ($M)	Space ($M)	Total R&D ($M)
Automation and Robotics		31.3	31.3
Communications Systems		8.5	8.5
Computer Science	16.7	6.5	23.2
Controls and Guidance	30.4	6.3	36.7
Data Systems		13.2	13.2
Human Factors	24.7	5.2	29.9
Sensor Technology		16.0	16.0

The NASA Civil Space Technology Initiative (CSTI) will be initiated in FY88 with the goal of revitalizing the nation's civil space technology capabilities and enabling more efficient, reliable and less costly space transportation and earth orbit operations. The IS&HF Division will have focused CSTI technology activities in High Speed/Capacity Data Systems, Science Sensors, Automation and Robotics. Funding for these activities are included above. In FY89 another new initiative, Pathfinder, is being planned. The objective of Pathfinder will be to develop and validate critical enabling technologies for future exploration missions. It is anticipated Pathfinder will include focused Information Sciences and Human Factors activities in Planetary Rover Technology, Optical Communications, Human Factors/Life Support, Automated Rendezvous and Docking, Adaptive Hazard Avoidance Landing, and Photonic Systems.

To aid in the communication of program efforts, the names and phone numbers of Headquarters program managers are included in this report along with the names and phone numbers of the key center technologists who conducted or managed the significant technology activities.

DIVISION DIRECTOR: Lee Holcomb, (202) 453-2747

DEPUTY DIRECTOR: Ray Hood, (202) 453-2745

NASA DIRECTORY

Center	Symbol
Ames Research Center Moffett Field, CA 94035	ARC
Ames Research Center Dryden Flight Research Facility PO Box 273 Edwards, CA 93523	DFRF
Goddard Space Flight Center Greenbelt, MD 20771	GSFC
Headquarters NASA/OAST/RC Washington, DC 20546	HQ
Jet Propulsion Laboratory 4800 Oak Grove Drive Pasadena, CA 91109	JPL
Lyndon B. Johnson Space Center Houston, TX 77058	JSC
John F. Kennedy Space Center Kennedy Space Center, FL 32899	KSC
Langley Research Center Hampton, VA 23665	LaRC
Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135	LeRC
George C. Marshall Space Flight Center National Aeronautics and Space Administration Marshall Space Flight Center, AL 35812	MSFC

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Automation and Robotics

OAST created the Civil Space Technology Initiative (CSTI) as a five-year effort to improve by an order of magnitude NASA space technology. Of particular concern has been the cost of NASA ground and flight operations, such that the CSTI program has focused significant resources on development and demonstration of automation and robotics technologies for space applications. Artificial Intelligence and Telerobotics when applied to the space environment have the capability to significantly improve productivity and enhance safety, as well as reduce the cost of NASA operations.

The automation and robotics program is divided into two areas, with Autonomous Systems focusing on the automation of control systems for the Space Station and mission operations and Telerobotics focusing on automation for in-space servicing, assembly, and repair. Each has a planned sequence of integrated demonstrations showing the evolutionary advance of the state-of-the-art. Applications demonstrations are planned at NASA Mission Centers for the transfer of the technology into the operations environment. Underlying the demonstrations are five research areas that will develop expertise in: sensing and perception; planning and reasoning; control execution; operator interface; and systems architecture and integration. Coordination with DARPA's A&R program is achieved since NASA acts as a DARPA agent. Memoranda of Understanding have been developed with Space Station for the transfer of OAST developed technologies to the Flight Telerobotic Servicer and the Thermal and Power Control Systems.

FY87 has seen the establishment, and significant initial accomplishments of the A&R program. The Telerobotics Program has achieved a major milestone towards completion of their first major technology demonstration through the vision-based tracking of a spinning satellite (once it is initialized by a human-guided graphic overlay), and the synchronized positioning of the manipulator arms. Three applications demonstrations were completed using the Beam Assembly Teleoperator. The applications were: assembling beam elements into a space structure; using a general control structure for coordinated movement of multiple robot arms; and using the Oak Ridge National Laboratory's teleoperated manipulator to recreate the Access experiment. The Autonomous Systems Program has achieved a major milestone towards the Space Station Thermal Control Expert System technology demonstration through the completion of System Build I which has led to the development of the Model Tool Kit. Accomplishments toward completion of applications demonstrations have occurred with the development of an operational readiness prototype expert system for the monitoring of the Shuttle communications systems and initial integration of the KATE and GMODS for diagnostics and control of the Shuttle Environmental Control System.

Major research goals were accomplished in the areas of: operator interface; systems architecture and integration; and planning and reasoning. In the operator interface element higher-performance force reflecting hand controllers and triggers were tested for teleoperation. In the systems architecture and integration element, the first design of the spaceborne symbolic processor was

completed with a reconfigurable, radiation resistant, fault-tolerant architecture. In the planning and reasoning element, a collaborative effort with DARPA began on research of intelligent communicating agents while the Autoclass probabilistic reasoning system produced striking new classes of spectral objects when applied to IRAS data.

In addition to the CSTI technologies, OAST has been reviewing the technology requirements for future planetary and lunar missions, and has packaged these into the new initiative called Pathfinder. In the area of exploration a significant amount of automation and robotics research will be focused on the development of a planetary rover that would act in the place of humans in the scientific discovery of the moon and Mars - semi-autonomously, with only occasional communication and direction from Earth. This is a challenging problem in that the rover would effectively be a mobile laboratory with its own instrumentation, tools and intelligence for self-navigation, and rock sample acquisition and analysis. This development effort is a requirement unique to NASA, and it will build on the in-house expertise in automation and robotics which has resulted from the CSTI program.

PROGRAM MANAGER: Dr. Melvin Montemerlo
NASA/OAST/RC
Washington, DC 20546
(202) 253-2744

Spaceborne VHSIC Multiprocessor System (SVMS)

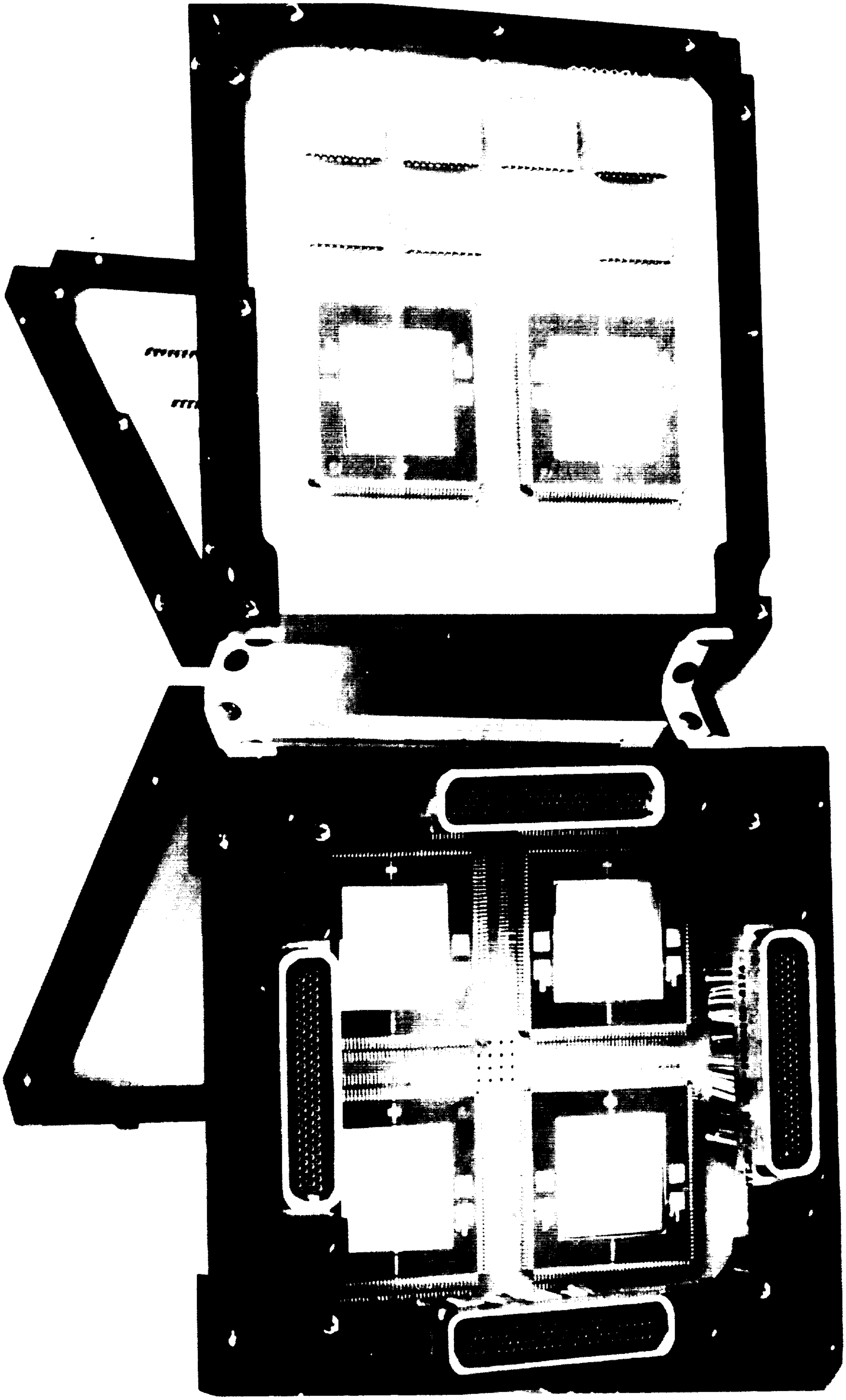
NASA is developing very large, intelligent knowledge-based systems for use in many applications, including power, guidance, communication, data management, and life support. In the Space Station environment, such systems will improve safety, increase crew productivity, and reduce maintenance and operating costs. High performance and flexibility are essential to a processing system capable of running these systems efficiently and reliably. The Spaceborne VHSIC Multiprocessor System will facilitate symbolic processing, the required enabling technology for high performance and flexibility in the operation of large, knowledge-based systems.

The major performance objectives of the Spaceborne VHSIC Multiprocessor System will incorporate speed more than ten times that of the Symbolics 3675, the current industry standard, ability to handle at least 22,000 rules with a minimum execution rate of 8000 rules per second, and high reliability and fault tolerance. Although uniprocessor technology is rapidly developing, a physical speed limit is being reached. Thus, a multiprocessor LISP machine is the most likely candidate for meeting the above requirements. In addition, the proposed radiation resistance is a minimum of 10^5 rads, the proposed input power is 350 watts, the proposed overall volume is one cubic foot, and the proposed overall weight is 50 pounds. Algorithms for fault detection, identification, isolation, and correction are also included as part of the architecture design.

Several advanced processing architectures are being studied to determine which will best meet both the symbolic and numeric computing requirements of very large intelligent systems. Some of the multiprocessor issues being studied are compiler recognition of parallel directives, process-to-processor scheduling and synchronization, garbage collection, processor-to-memory connection, multi-module global memory management, degree of coupling, granularity, and virtual memory and virtual machine design in a multiprocessor system. In addition, a testcase workload to evaluate performance of the delivered architecture is being developed. Standard numeric benchmarks are being translated from Fortran to LISP to run on the symbolic architecture. Also, a testcase application criteria taxonomy is being constructed. Another major effort is an interprocessor communication study. That is, a method is being developed for determining parallelism in large knowledge-based programs and for distributing the components on multiple processors. An unqualified brassboard version of the Spaceborne VHSIC Multiprocessor System is expected during 1990. Programming languages include Common LISP and Ada.

TECHNICAL CONTACT: Marc Hosein, ARC (415) 694-6526

SPACEBORNE (VHSIC) MULTIPROSSOR SYSTEM (SVMS)



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Prototype Development for the Thermal Expert System TEXSYS

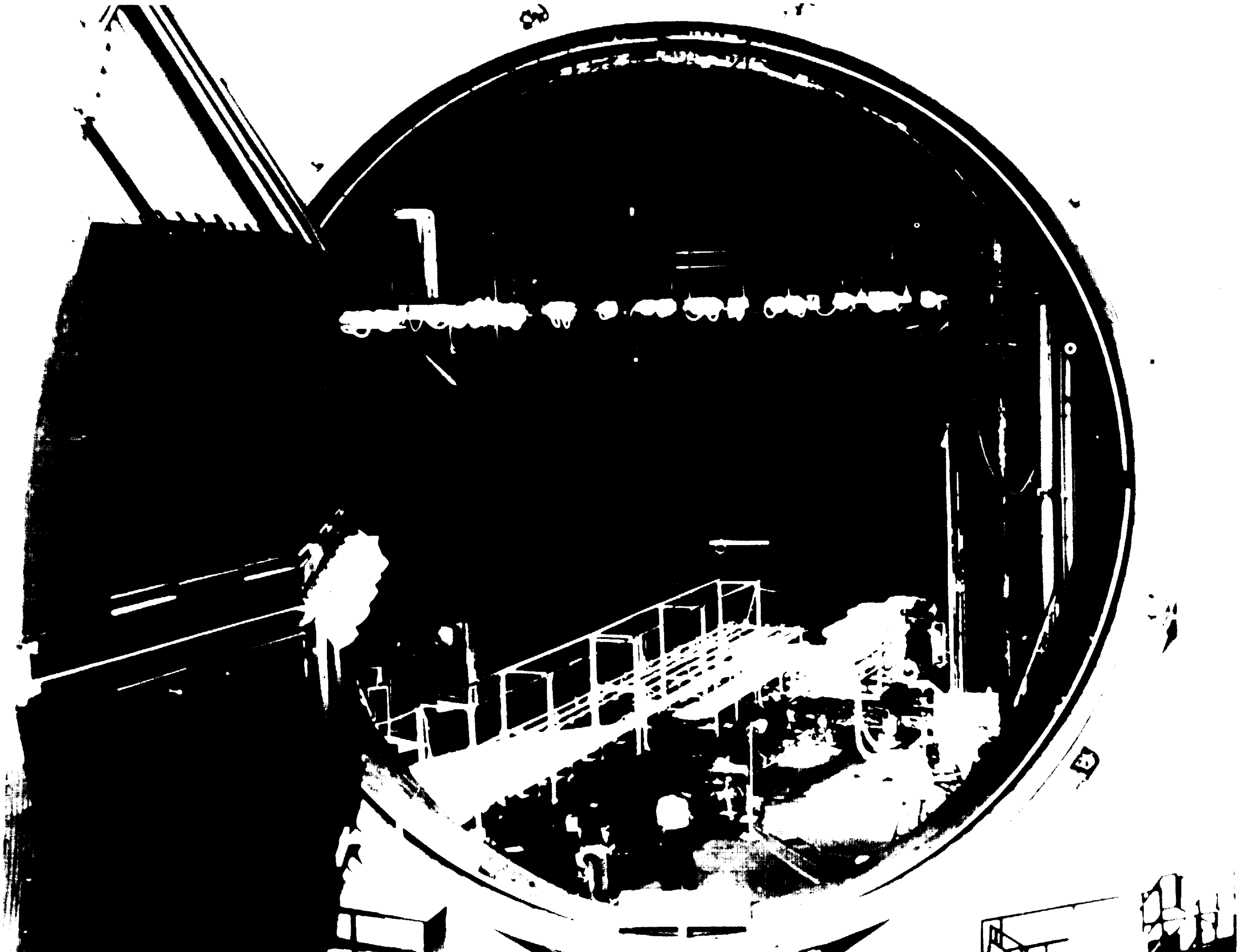
Work has proceeded on the development of the Thermal Expert System (TEXSYS) designed to perform monitoring, control, trend analysis, fault recognition and diagnosis and limited reconfiguration of the Thermal System for Space Station which are under development in a thermal testbed at Johnson Space Center. Work so far has consisted of the development of two preliminary research prototype expert systems and the beginning of the system builds 1-5.

Work on the two prototypes has provided the opportunity to evaluate KEE and Simkit, which led to development of a new expert system tool, MTK (model tool kit). Through the prototypes, various approaches to technical problems presented in the construction of knowledge-based system for the Thermal Testbed were investigated. Preliminary knowledge engineering leading to the development of causal models for general thermal domain as well as on particular thermal testbed configurations were performed. Results from prototype development are now being utilized in the design of the Major Milestone Systems, the System Builds 1-5, for 1988 demonstration of the Systems Autonomy Demonstration Project Office.

The SADP project office has initiated research for meeting the goals of the 1988 Demo of the thermal expert system. These research areas have included the following: 1) causal modeling; 2) verification and validation methods for NASA use on expert systems; 3) methods for reliable decisions when faced with uncertainty in a mixed symbolic and algorithmic real-time system; and, 4) methods for resolving supporting and conflicting evidence for deduced parameter values.

TECHNICAL CONTACT: Carla Wong, ARC (415) 694-4294

THERMAL TESTBED INSIDE VACUUM CHAMBER AT JOHNSON SPACE CENTER



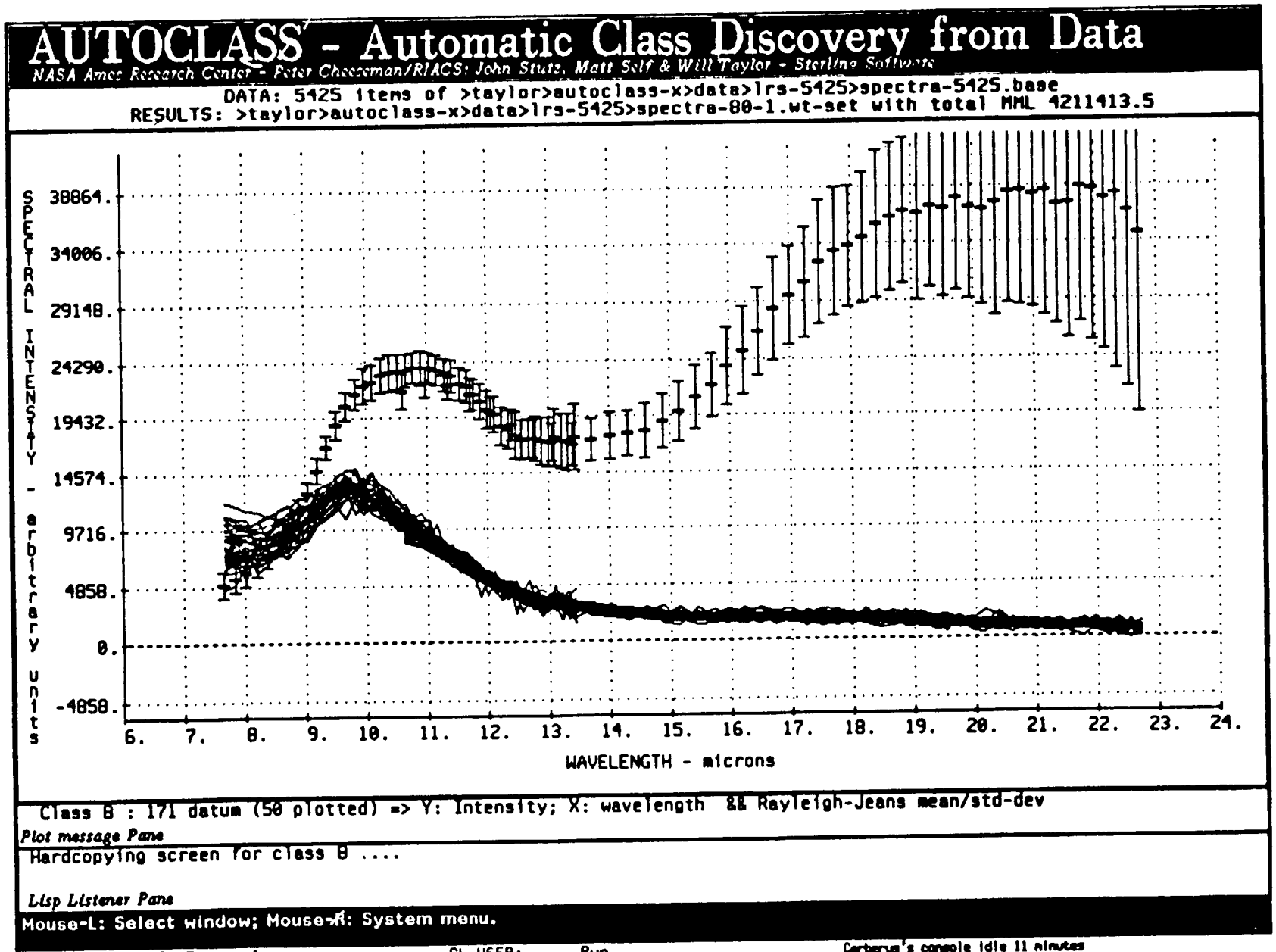
Probalistic Reasoning Approach Applied To Astrophysics Data

The Artificial Intelligence Research Branch of the Information Sciences Division of NASA Ames has developed a database introspection system which can classify data without any prior classification information supplied by the user. (Previous classification techniques required input from the user such as the number of classes to be extracted from the data, or even the nature of the classes.) This system not only generates an unbiased description of the data presented to it, but also generates a measure for the "goodness of fit" of the description of the data--essential when dealing with noisy data. When applied to a portion of the IRAS Low Resolution Spectrometer catalog, the system almost immediately generated striking results, including some previously unacknowledged spectral types. These classes are presently being studied by Infra-Red astronomers at Ames. Additionally, astronomers at the Space Telescope Science Institute in Baltimore, as well as others at the European Southern Observatory in Garching, have used the system to classify various other astronomical databases. When the results of the Autoclass system were presented at an invited talk at the recent International Conference on Astronomy from Large Databases, the results generated considerable interest, as well as several requests for independent corroboration of classification work in progress at various institutes around the world.

This system was developed as an initial step of a research program in machine learning. Future work will incorporate an explanation capability, enabling the system not only to classify data, but to justify its results to the user.

TECHNICAL CONTACT: Peter Cheeseman, ARC (415) 694-6525
Don Rosenthal, ARC (415) 694-4946

ONE OF THE APPROXIMATELY 70 CLASSES AUTOCLASS EXTRACTED FROM THE IRAS DATABASE. The dark band below contains the raw spectra of the stars in the class, distinguished by a common emission peak at 9.8 μm. The upper curve represents the adjusted mean and standard deviation at each wavelength.



Intelligent Communicating Agents

The Information Sciences Technologies Office of DARPA and NASA Ames Research Center have recently signed a Memorandum of Understanding (MOU) for cooperation in areas of mutual interest in artificial intelligence research. As the first activity under the terms of the MOU, a $1.5M/year research project into Intelligent Communicating Agents has been initiated under the technical control of the Artificial Intelligence Research Branch of the Information Sciences Division of ARC.

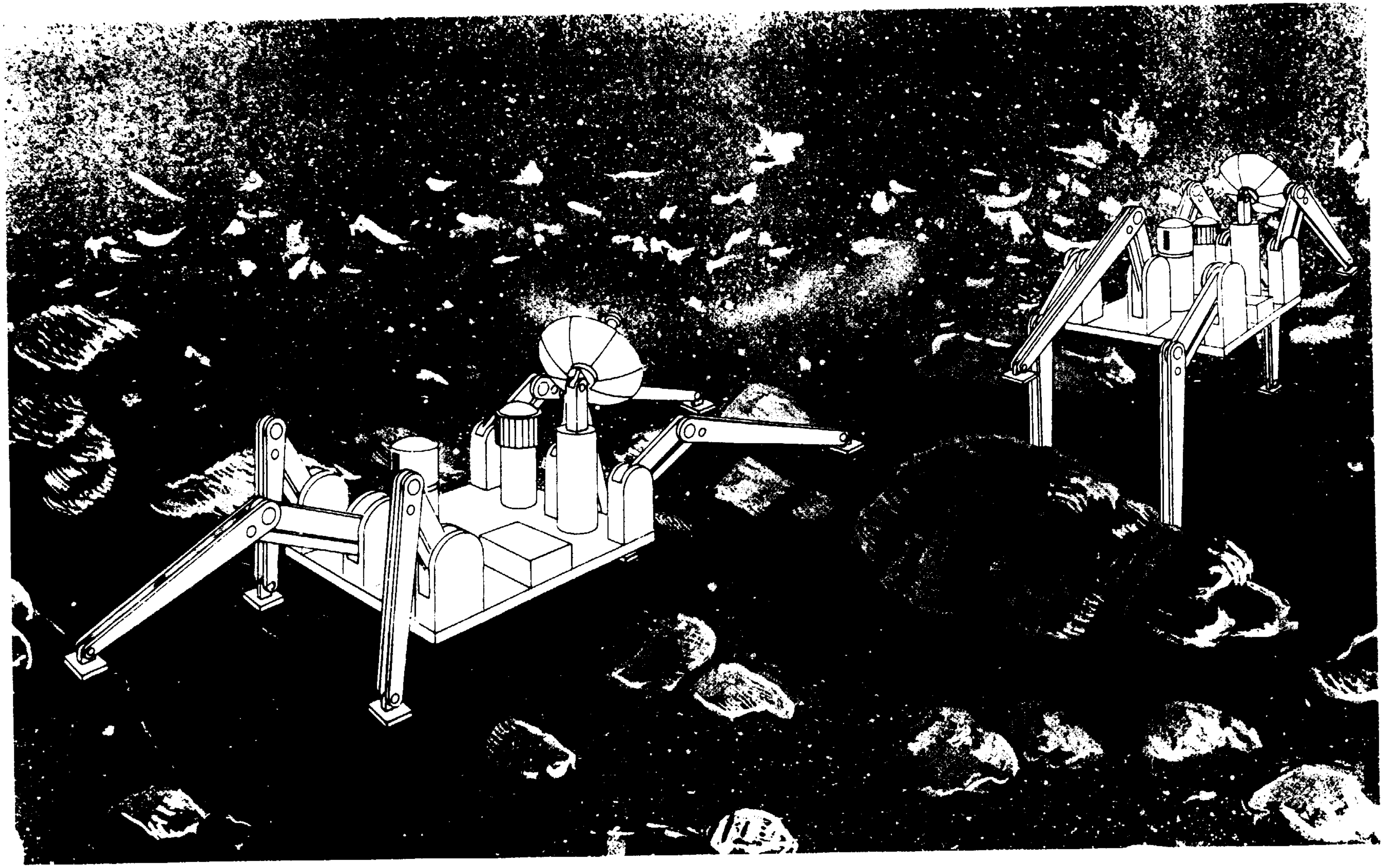
The project involves collaboration among Stanford University Computer Science Department, SRI International Artificial Intelligence Laboratory, Rockwell Palo Alto Science Center, and ARC AI Research Branch. The Principal Investigator is Professor Nils Nilsson of Stanford, one of the world's leading AI research scientists. The work will focus on basic research into the mechanisms necessary to communicate goals, beliefs, and intents among intelligent agents, implementation of those mechanisms in mobile robots, and development of detailed technology transfer pathways into potential NASA domains, particularly evolutionary Space Station Construction, and Planetary/Lunar Base Construction.

The project team is unique in its broad and deep knowledge of basic AI science (Professor Nilsson's group is one of the two or three best in the world in logic-oriented approaches to problem-solving), robotics (SRI continues to be a leading national center for work in mobile robots), and NASA domains (Rockwell and ARC bring that expertise to the project). A steady stream of applications developments is expected to emerge during the life of the project. The topic of cooperative problem solving among intelligent systems has been identified as one of the most important to the Systems Autonomy Technology Program and this work is perhaps the most significant national effort in the area.

Other NASA/ARC--DARPA joint projects in 1988 will include work in Formalized System Development and Explainable Expert Systems at University of Southern California Information Sciences Institute and Truth Maintenance System-Based Planning Tools at IntelliCorp, Inc. of Mountain View, California.

TECHNICAL CONTACT: P. Friedland, ARC, (415) 694-4277

INTELLIGENT AGENTS COOPERATING IN SITE PREPARATION FOR A MARTIAN BASE



STS Flight Control Room Operations - INCO Expert System
Operational Readiness Demonstration Prototype

The objective of this demonstration is to develop an expert system for monitoring Space Shuttle communications and instrumentation systems which can be used to evaluate if expert system technology is sufficiently mature for use in decision making where human lives and major NASA vehicles are in jeopardy.

Task automation algorithms for fault detection of shuttle communications and instrumentation systems had previously been defined by Mission Operations Directorate personnel at JSC. Rules for an expert system to monitor Space Station communications systems had also been developed by these personnel. In this project the task automation algorithms will be coded on a UNIX workstation and combined with a rule based expert system built from a modified rule base from the earlier space station efforts. A standalone telemetry processor will be interfaced to the workstation and then integrated into the Shuttle Mission Control Center data system.

Evaluations will initially be performed in a laboratory environment utilizing shuttle telemetry tapes. After confidence is gained in the combined automation/expert system, it will be moved to the Flight Control Room in the Mission Control Center for use in integrated simulations. It will initially be used as a consultant to an experienced flight control team, then as a component of a "reduced" team with fewer operators to evaluate the use of the expert system to lower manpower requirements. After extensive testing, the system may be used as a consultant during actual shuttle flight, if sufficient confidence can be gained in the system.

TECHNICAL CONTACT: John Muratore, JSC (713) 483-0796

THE SHUTTLE MISSION CONTROL CENTER PROVIDED THE ENVIRONMENT FOR EVALUATING REAL-TIME EXPERT SYSTEMS THROUGH THE FLIGHT CONTROL DEMONSTRATION PROGRAM

Diagnostics and Control for Launch Processing Systems

The objective of this research is to develop and demonstrate the system's autonomy "core technology" software and hardware necessary to accomplish autonomous diagnostics and control of interactive complex electro/mechanical launch processing systems. The autonomous system will perform the duties of a systems engineer better than the best NASA systems engineer.

Parallel development of "core technology" diagnostics and control software: i.e. the ARC development using KEE on the Space Station Thermal Control System hardware at JSC; and the two parallel KSC development efforts of KATE and GMODS demonstrated against actual Launch Processing ground hardware, will provide assurance that the most robust software architecture is developed for use on Space Station, future ground processing systems, and mission control systems.

The existing KSC Knowledge-based Autonomous Test Engineer (KATE) diagnostics and control software and the, under development, Generic Model-Based Diagnostic System (GMODS) software will be merged into one autonomous diagnostics and control set of software and be demonstrated showing single system diagnostics and control using the KSC Pad B Environmental Control System in 1988. The software will be modified for interactive multiple systems to be demonstrated against the OPF Bay 3 ECS, Pneumatics, and Power systems in 1991. Development will be by in-house NASA personnel except for early years of MITRE knowledge engineering consultation. Existing in-house development hardware will be used.

Current ECS manpower levels in the operational system require two console personnel operating on a three shift basis when operating in the local control mode. Additionally, two system level engineers support on a two shift basis. With the implementation of the Autonomous Launch Processing System it is projected that the console operator level can drop to one operator per shift, for a total ECS operational manpower reduction of 37.5%. The manpower required for the ECS operations is typical of the some seventeen LPS systems and it is expected that this percentage reduction will be experienced throughout the operations when full systems autonomy is implemented within LPS.

TECHNICAL CONTACT: John Jamieson, KSC, (305) 867-3224

SHUTTLE LAUNCH

Space Station Power Subsystem Automation

The objective of this research is: to apply, evaluate, and demonstrate autonomy technologies to space power system autonomous operation; to determine modes suitable for autonomous operations; to develop or acquire and apply the requisite autonomous technologies, power system technologies, "core" supporting technologies; to demonstrate autonomous operation of subsystems, where appropriate, operation of a space power system operating as part of the coordinated control demonstration of two expert systems; to verify the benefits of autonomous mode operation; and to provide power system training and design assistance for space power systems.

The accomplishments planned for this scenario are: component test bed design FY 87, fabrication FY 88; system test bed and DAS design FY87, fabrication FY88; develop methodologies/software for autonomy "control/management" functions FY87-89; knowledge base finalized FY89; identify/acquire "core technologies" FY87-89; demonstrate autonomous component operation FY88; identify/develop human interface requirements FY88-89; demonstrate stand alone system operation FY90; demonstrate combined system operation (power/thermal control); develop training manual/procedure for power system operators FY90-91; determine best method of power system operation FY88-90; and verify the best method of system operation FY90.

The output of the Power System Autonomy Demonstration task will consist of an accumulation of autonomy technology expertise in the operation and management of space power systems and the resource they produce; on board electrical power and energy. Much of this expertise is also applicable to and will apply to other space systems than power. Specific identifiable outputs are as follows.

Products/Deliverables: 1) fault detection/classification/isolation methodologies; 2) system restoration strategies; 3) planning/replanning in the face of uncertainty for the use of the power/energy resource aboard a space system; 4) operator training methodologies for power system operation and resource management; and 5) extensive data base on the application of EB/AI technologies to the design and autonomous operation of space systems.

Operation of mature autonomous space systems has the potential for significant reductions in operational support costs. Improved reliability of operation of such spare systems is also a benefit.

Assumptions/Conditions are: 1)most hardware for component testing is available from other sources (limited funding is included for component/device hardware); 2) no testbed procurement funding is included from this RTOP (Data Acquisition and Control System is included); 3) funding to support tests beyond 1990 is not included; and 4) resources to "link" systems for combined systems tests in 1990 (satellite link between centers, for example) are not included.

TECHNICAL CONTACT: Carla Wong, ARC (415) 694-4294

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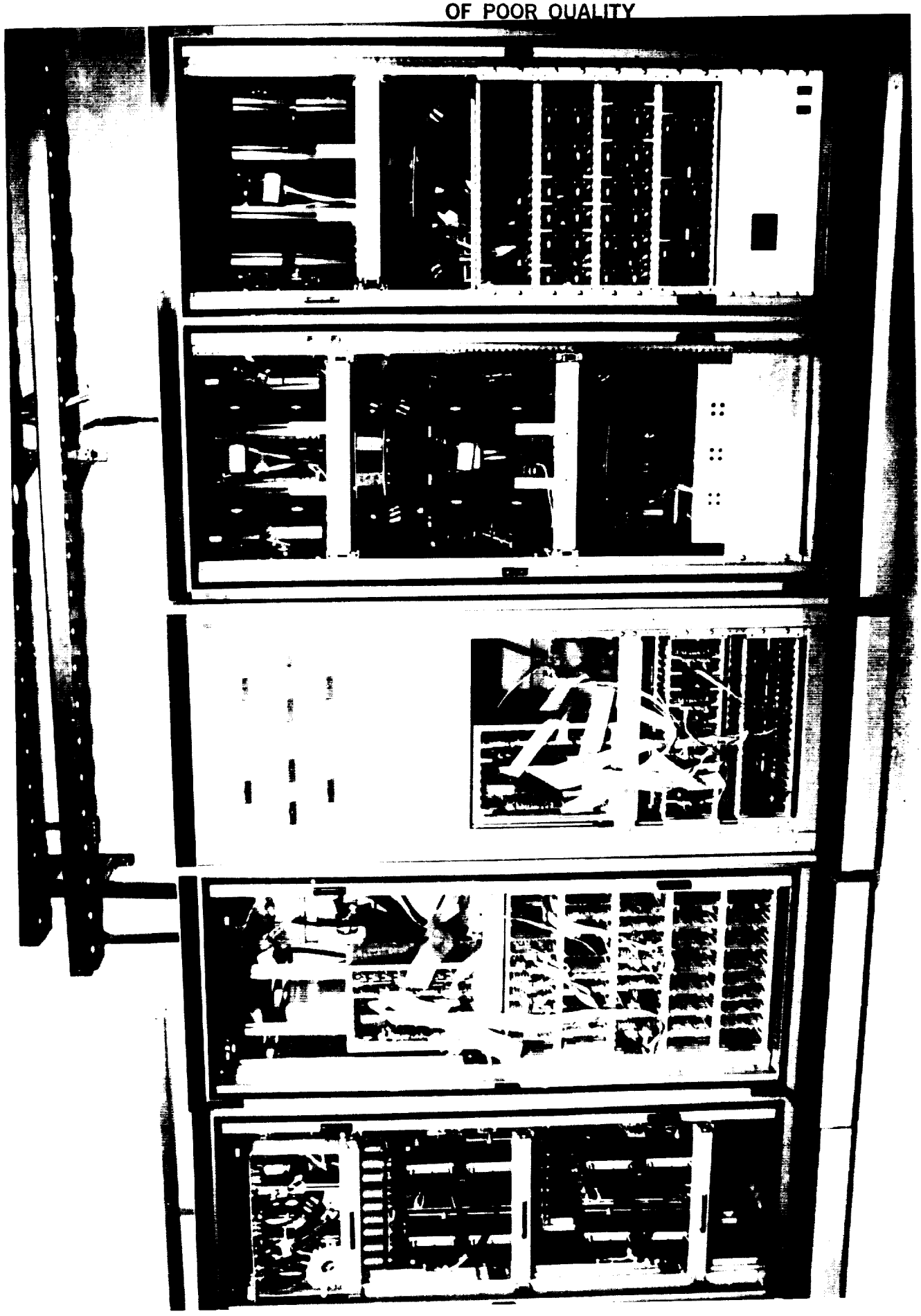
20 KH_z (KILOHERTZ) POWER TESTBED AT
LEWIS RESEARCH CENTER



Control of Multiple Robot Arms

A general control structure for coordinated movement of multiple robot arms has been implemented. An operator commands an object to move with a velocity (velocity control) in a desired direction, with respect to a selected axis system. Commanded velocity is resolved into robot arm joint rates. Multiarm coordination is achieved by choosing the same object and movement reference frame for each robot arm. Position control -- "go to" commands: (x, y, z; orientation) -- which allows the building of high-level move commands (scripts or task primitives) is also based on this structure by using a velocity proportional to the position error. The control structure incorporates force/torque compensation to null the gravitational effects and for active compliance to control undesired forces.

This picture shows dual robot arm control. The operator, sitting in front of a computer terminal, selects an axis system at the center of a long construction beam. Then, with a six-axis hand controller, he commands the beam to move (translation and rotation) in a certain direction. In response, both robot arms move the element in a coordinated manner in the commanded direction. Force/torque sensors at the robot wrists are used to null gravity effects and provide manipulator compliance.

TECHNICAL CONTACT: L. Keith Barker, Donald Soloway, LaRC (804) 865-3871

DUAL ROBOT ARM CONTROL

Space Truss Assembly Using Teleoperated Manipulators

The assembly of a truss structure by two EVA astronauts in the bay of the space shuttle was successfully accomplished in the Access I experiment on flight STS 61b in November 1985. To demonstrate the capability of current teleoperated manipulators to accomplish realistic space assembly, the Access experiment was repeated in a ground-based laboratory using a teleoperated manipulator. The accompanying photographs show the laboratory tests in progress at the Oak Ridge National Laboratories using the Central Research Laboratory's model M-2 master/slave servo manipulator. The hardware employed was a combination of that actually used on the Shuttle and that used to train the astronauts in water immersion facilities for the experiment. Two astronauts were required for the flight assembly. In the ground-based demonstration the manipulator system was substituted in the role of one of the astronauts while a person in shirt sleeves performed the role of the other astronaut. The experiment was repeated a number of times to acquire balanced quality-of-performance statistics by varying the roles of the manipulator and the human assembler and of the manipulator operators as well. None of the equipment was modified to accommodate the experiment. As can be seen in the photographs, a construction fixture was used to hold the nodes and columns (the basic elements of the truss) in place as the assembly progressed.

The most important result found was that, in fact, the unmodified manipulator system has sufficient dexterity to do the job. As was expected it took longer to complete the task using robotics - about three times as long on the average. Also a relatively small number of components were dropped or otherwise mishandled, an occurrence which could not be permitted in space. However, it is believed that these mishaps could be eliminated entirely by training and/or equipment modifications.

TECHNICAL CONTACT: Walter W. Hankins, III, Randolph W. Mixon, LaRC (804) 865-3871

TELEOPERATOR STRUCTURAL ASSEMBLY TASK

Vision-Based Satellite Tracking and Robotic Grappling

Vision-based tracking of spinning, nutating, and tumbling satellites or other space objects will allow free-flying telerobots to grapple and dock with these objects as the first step in a maintenance, repair, or assembly operation. Human reactions are not fast enough to track and grapple some spin-stabilized satellites, which can rotate up to 50 RPM. Astronaut grappling has been accomplished at 1 RPM (with and without the use of the RMS arm). The objective of this effort is to demonstrate robotic grappling, initially between 0.5 and 1 RPM, and later at much higher speeds.

A six degree-of-freedom satellite mock-up is suspended from a counterweight and a universal joint, allowing smooth simulation of zero-g dynamics. A five-camera sensor array views the satellite, and a custom pipelined image processor extracts features from the images, such as edges and vertices. These features are matched to an internal object model for acquiring the position and orientation of the satellite, and for tracking. Visual tracking data is used to guide the manipulator and effectors to the grapple fixtures. At the instant of physical contact, control of the arms is switched from vision-based position control to hybrid position-force control, with the wrist force-torque sensors providing the information needed to gently decelerate the relatively massive satellite within the force capabilities of the arms.

Vision-based tracking of the satellite has been accomplished at 9.7 RPM, with a standard deviation at the grapple fixtures of 1.6 millimeters. This accuracy is well within the 5 mm which allows proper grappling. Also, tracking of the satellite with visual labels (e.g. 'running lights', needed during the 'night' portion of each orbit) has been demonstrated at 13.7 RPM. The tracker is currently initialized by a human-guided graphic overlay. Synchronized motion of the position and orientation of the manipulator arms with the tracking data has been demonstrated. Hybrid position-force control of the manipulators has also been demonstrated.

A single-arm automated grappling of the satellite at 0.5 RPM is planned for December, 1987. Dual-arm grappling at 1 RPM, with fully automatic tracking initialization, tracking, grappling, and docking, is planned for December, 1988. A 20 RPM tracking and grappling experiment is planned for FY90.

TECHNICAL CONTACT: B. Wilcox, JPL (818) 324-4625

GRAPPLING OF SPINNING SATELLITE USING MACHINE VISION AND FORCE CONTROL

Operator Interface

The objective of this work is to develop a technology base for efficient allocation of functions between humans and automation in space telerobotics. Areas of technology development are: (1) operator's performance as enhanced by force feedback; (2) operator's performance as influenced by different hand controller control modalities; (3) display techniques of visual and non-visual sensor information, including stereo vision; and (4) hardware development to support the above evaluation and analysis.

The approach taken toward this end was to: (1) conduct experimental performance studies for operating a force-reflecting hand controller (FRHC) under different position/rate control modalities with different parameters, including deadband and gains; (2) conduct experiments with a force-reflecting hand trigger, using different trigger modes and control gains; (3) Perform human stereo versus mono vision experiments in static discrimination and dynamic teleoperation experiments; (4) develop hardware, mechanisms, electronics and software to perform the above experiments; and (5) to contract MIT, UCB, and NOSC in major study efforts in supervisory control, advanced graphics control, and tactile sensing and control.

Thus far, the following have been achieved: (1) FRHC task performance evaluation via graphics simulation was performed leading to conclusions on choices of control parameters; (2) force-reflecting hand trigger system was completed, debugged, and evaluated, leading to conclusions on the effectiveness of such a mechanism; (3) a bench model of a single-camera stereo system was developed; evaluation will take place in FY88; (4) hardware design was specified for a multiple mono camera system to support future human vision experiments, and (5) midyear reports from MIT, UCB and NOSC contract work were received. Contract renewals are in process.

Empirical findings from performance experiments on the FRHC and force-reflecting hand trigger permit a better utilization and thus higher performance using the controller devices. Data collection and analysis software developed for the above will be adapted to future experiments, including the Telerobot Demonstration experiment and OMV smart end effector projects. Human vision experiments and multiple camera viewing/automatic control will lead to more efficient teleoperation strategies.

Future plans are: (1) to continue with ongoing experiments and data evaluation; (2) to complete the camera system design, then to implement the multi-camera system; (3) to design and perform dual-arm teleoperation experiments; and (4) to incorporate research contract results into Telerobot System.

TECHNICAL CONTACT: Antal K. Bejczy, JPL, (818) 354-4568
Edwin P. Ken, JPL, (818) 354-2726

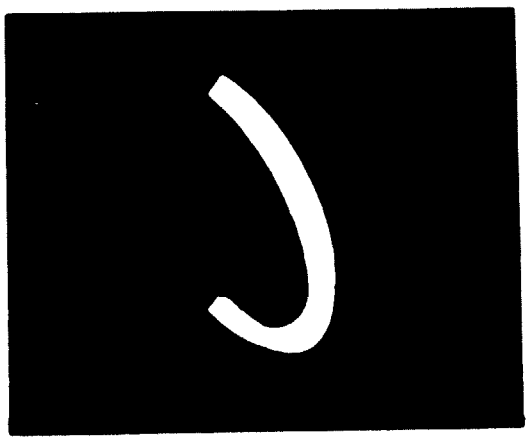
OPERATOR INTERFACE

FORCE-REFLECTING
HAND TRIGGER

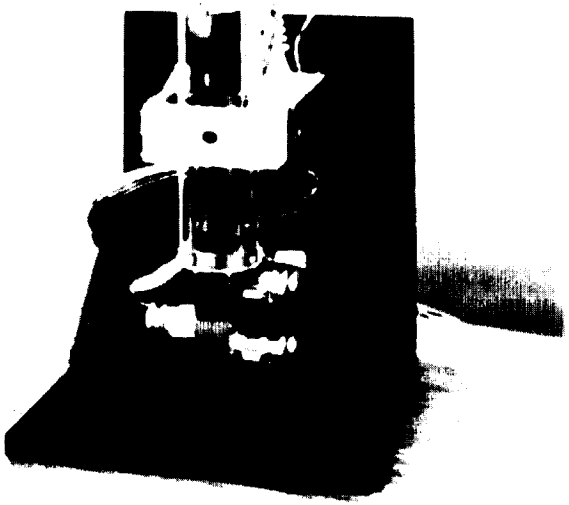
UNIVERSITY/MISC CONTRACTS

- MIT - COOPERATIVE DEXTEROUS TELEOP RESEARCH
- UCB - VISUALLY COUPLED TELEOP SYSTEMS
- NOSC - TACTILE DISPLAY TECHNOLOGY
- LAMMA ENGR - SINGLE-CAMERA STEREO SYSTEM

- EXPERIMENTAL PERFORMANCE STUDIES - FRHC USING DIFFERENT CONTROL MODALITIES. FORCE-REFLECTING HAND TRIGGER EVALUATION
- HUMAN VISION EXPERIMENTS
- MULTI-MONO CAMERA AND SINGLE-CAMERA STEREO SYSTEMS DEVELOPMENT
- NEW FRHC HAS INTEGRATED MULTI-FUNCTION HAND GRIP



SIMULATION GRAPHICS
FOR TASK PERFORMANCE
EVALUATION



NEW 6-DOF FORCE REFLECTING
HAND CONTROLLER (FRHC) PLUS
HAND GRIP (WITH TRIGGER
AND FUNCTION BUTTONS)

Beam Assembly Teleoperator (BAT)

The Beam Assembly Teleoperator (BAT) is a dexterous teleoperator originally designed for assembling the same structures used in previous MIT EVA assembly tests and in the EASE flight experiment. In its current configuration, the unit is equipped with one five-degree-of-freedom manipulator, a specialized grappling arm, a second specialized arm for large-angle beam rotations, and two monochrome stereo video camera pairs; it is mounted on a mobility unit with unconstrained motion in all six rotational and translational axes.

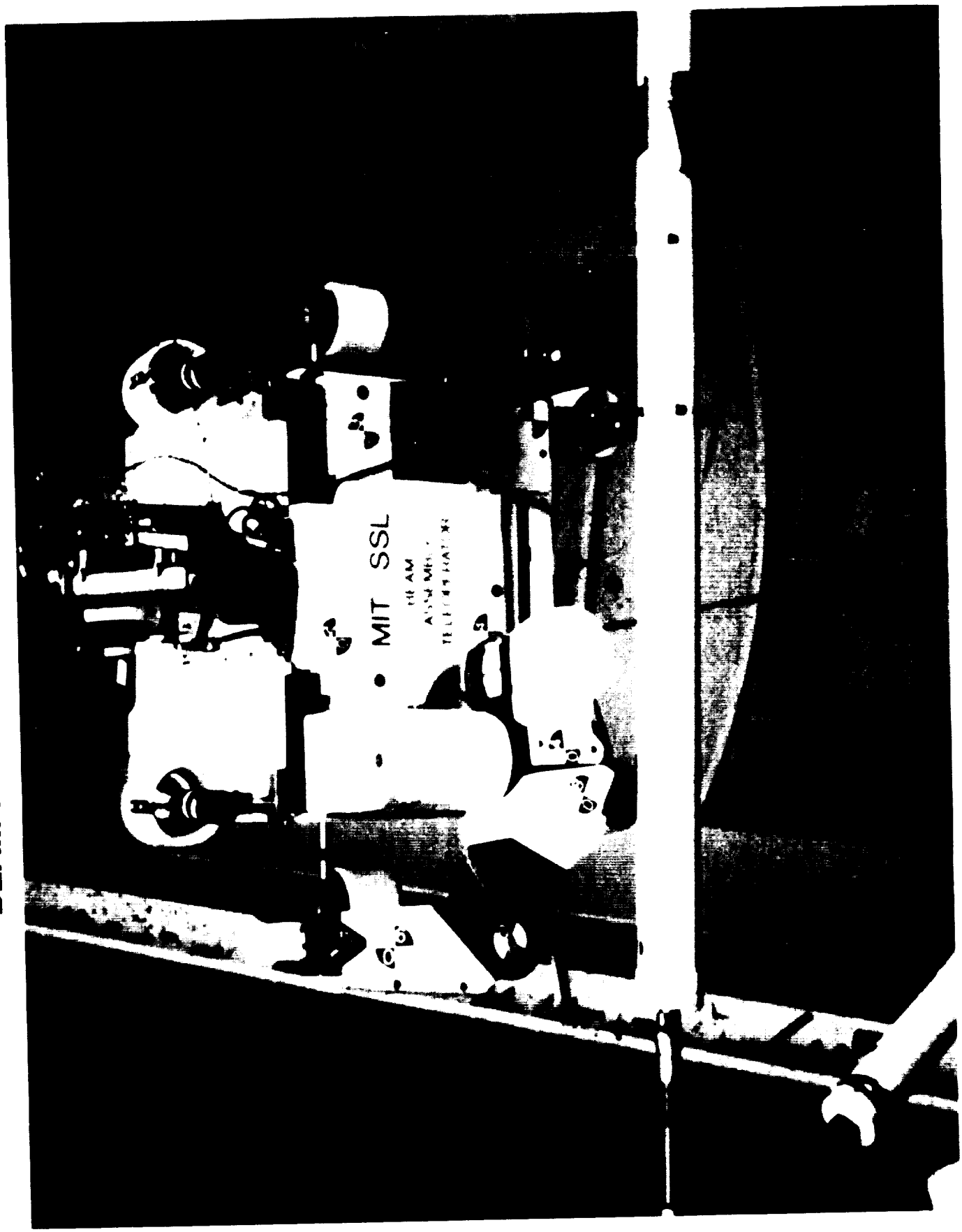
In the past grant year, the Beam Assembly Teleoperator has demonstrated all functions necessary for fulfilling the task its name implies: assembling beam-type elements into a space structure. The long initial development process culminated in January, 1987, with the successful construction of both an EASE-type tetrahedral structure and a space station truss structure by the BAT in tests at the NASA Marshall Neutral Buoyancy Simulator. Since that time, BAT has been undergoing a series of upgrades to increase its capability for autonomous operations and higher-level supervisory control: this increased robotics capability will be tested in the coming year for repetitive assemblies of space structures in tests at NASA Marshall and at MIT. Performance in these tasks will be correlated with learning and EVA experience, and will be used to provide quantitative evaluation of alternate BAT configurations and technologies described in later sections.

In the coming year, tests will be made of color cameras, to determine the utility of color in selected video applications. The expanded range of video coming back from BAT will be made more usable through a computer-controlled video switching system in the BAT control station, allowing the operator to chose stereo or doubled single views to the helmet-mounted monitors, and rack-mounted monitors in the control station. Another priority in the video system is to obtain the necessary hardware to allow computer graphics overlays on the video images. This will provide advanced capabilities in operator feedback, and should markedly increase BAT productivity.

Although BAT capabilities are sufficient for a variety of tests, as seen above, it is reasonable to implement a development path for modular upgrades to improve reliability and capabilities of the teleoperator systems. In the past year, this included the addition of the second stereo camera pair, and the development of a second specialized arm used for grappling beams and roughly aligning them with the structural connector. In the coming year, it is expected that upgrades will include a revised end effector for the right arm, capable of supplying force information to the arm control system, as well as greater grasp envelopes and forces, and proportional force control.

TECHNICAL CONTACT: Dave Aiken, MIT (617) 253-3626

BEAM ASSEMBLY TELEOPERATOR



Satellite Robot Simulator Vehicle

The Satellite Robot Simulator Vehicle (SRSV) is an air-cushion-based satellite simulator that reproduces in the two dimensions of its supporting table surface the free, low-friction motion of a satellite that is free floating in space. The SRSV represents a satellite robot that would perform (with greater ease and safety and at reduced cost) extravehicular functions in space similar to those currently performed by astronauts. The vehicle includes a two-link, two-degree-of-freedom manipulator that parallels the one that would be attached to such a space robot, and that operates in the two dimensions of the table surface. The table is 6' by 12', 10-ton granite surface plate with its top surface ground to an accuracy of .001". The accuracy provides a very flat and level surface that eliminates gravity-induced accelerations of the vehicle, and allows support of the vehicle by a very slow flow of gas to the air cushion.

The SRSV resembles as far as possible a practical and fully self-contained satellite robot. Visible in the photograph are gas tanks and regulators for supply of air-cushion and thruster gas; on board computer (card cage to right); analog and motor driver electronics (card cage to left); translational and rotational thrusters (triple set at lower right and single translational thruster mounted atop analog card cage); one of the two on board batteries (grey object in foreground); gas flow control valves (beneath analog card cage); power conditioning electronics (beneath computer); two-link arm (at left, incorporating black motors mounted low and digital joint-angle encoders mounted above); and the onboard camera mounted on the boom overlooking the arm.

The object of the research undertaken was to learn to control its arm, or the arm of an actual satellite robot, while compensating for the unavoidable dynamic coupling between motions of the arm and motion of the base itself. This is the same effect an astronaut freely floating in space would experience, whereby the act of reaching for an object would cause his own body to withdraw from the object. The reaching motion would therefore need to be exaggerated somewhat in order to obtain the desired object. The object of control of the SRSV arm is the same: to control accurately the position of the end-effector (arm tip) relative to an inertial object while freely floating, compensating for the free motion of the robot body. This is distinct from the case of industrial robots, which have fixed bases from which end-effector control may be achieved simply by control of the individual joint angles of the robot.

Control of the SRSV arm is achieved by employing a complete dynamic model of the system to establish a relationship between the torques applied at the arm joints (shoulder and elbow), and the accelerations of the arm tip (in x andy). The torques necessary to achieve a specified set of accelerations necessary to achieve arm-tip trajectory tracking may then be calculated from this relationship. Precisely the same techniques may be generalized to the more complex case of controlling a three-dimensional space robot. The on board television camera, combined with special image processing electronics, is used to track the position of the arm tip and the position and orientation of its target, arm and target being marked with infrared light-emitting diodes that appear very bright to the filtered camera.

TECHNICAL CONTACT: Professor Robert H. Cannon, Jr., Stanford U. (415) 723-3601

SATELLITE ROBOT SIMULATOR VEHICLE

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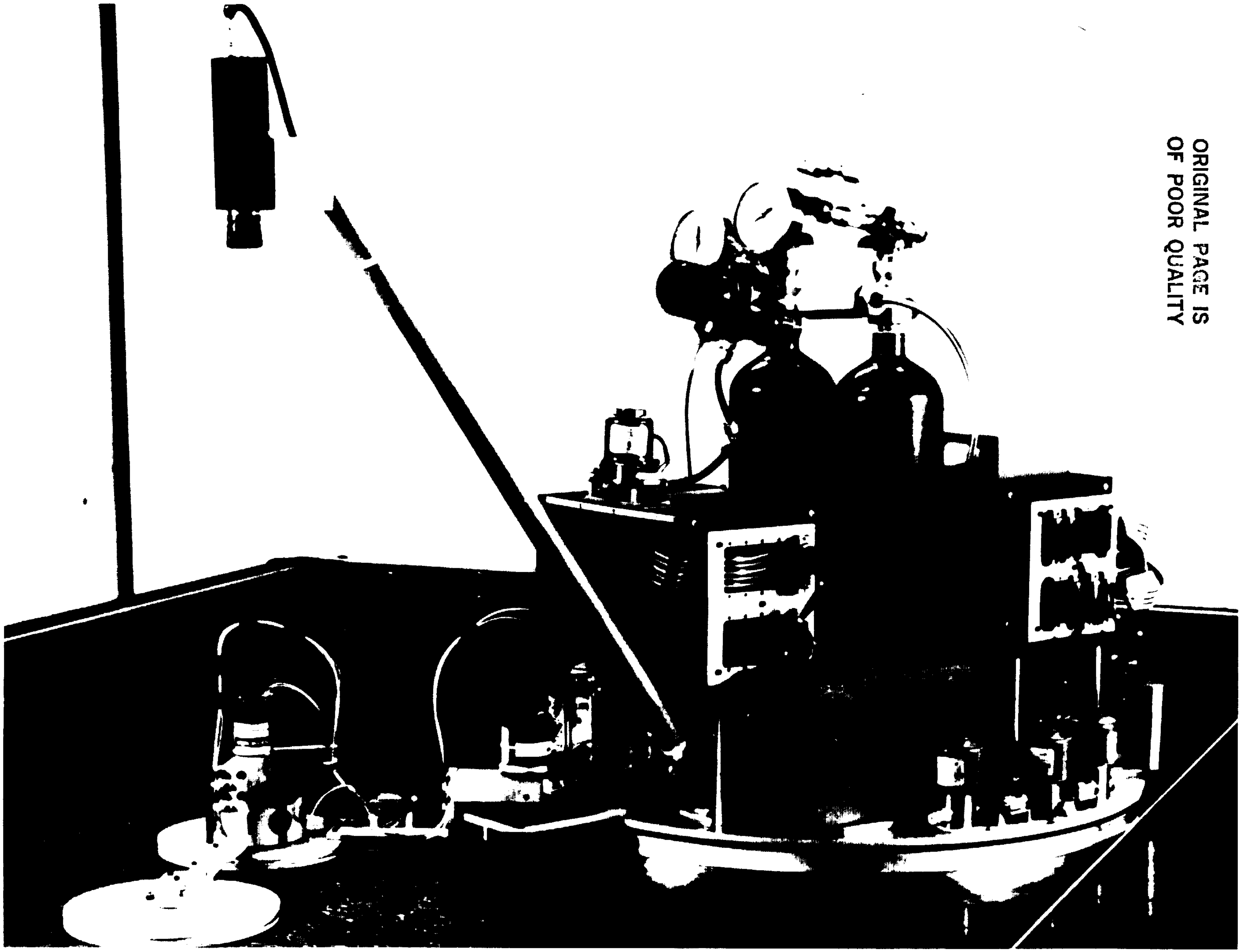


Communications Technology

The objective of the Communications Technology Program is to enable data transmission to and from low Earth orbit, geostationary orbit, and solar and deep space missions. This can be achieved by maintaining an effective, balanced effort in basic, applied, and demonstration prototype communications technology through work in theory, experimentation and components.

The program consists of three major research and development discipline areas. They are: (1) microwave and millimeter wave tube component research and development; (2) solid state monolithic integrated circuit research and development; and (3) free space laser communications component and device research and development. The research ranges from basic research in surface physics (to study the mechanisms of surface degradation under high temperature and voltage operating conditions which impacts cathode tube reliability and lifetime) to generic research on the dynamics of electron beams and circuits (for exploitation in various micro- and millimeter wave tube devices). Work is also performed on advanced III-V semiconductor materials and devices for use in monolithic integrated analog circuits (used in adaptive, programmable phased arrays for microwave antenna feeds and receivers) - on the use of electromagnetic theory in antennas and on technology necessary for eventual employment of lasers for free space communications for future low earth, geostationary and deep space missions requiring high data rates with corresponding directivity and reliability.

PROGRAM MANAGER: Martin M. Sokoloski
NASA/OAST/RC
Washington, DC 20546
(202) 453-2748

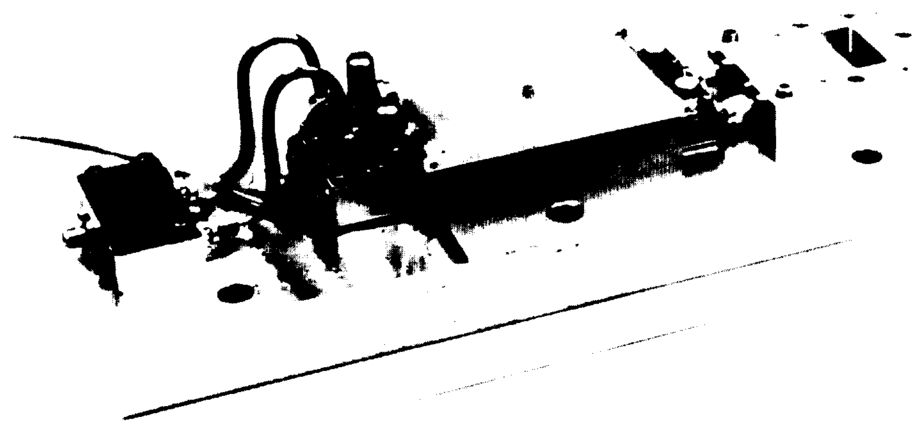
Efficient X-Band Solid State Power Amplifier Technology

Deep space communication create a unique set of requirements over and above those for the near earth environment. These include transmitters with high reliability, long life with high RF and dc efficiencies. Efficiency is an increasingly important concern with outer planet missions, such as those planned under the Mariner Mark II project, since they must use expensive electric power generation equipment (RTGs at $200K/W). Therefore, every effort is being made to lower power consumption, including use of the lowest transmitter power possible. The requirements for long life and reliability imply the use of solid state RF power amplifiers, but at high frequencies, the RF and dc efficiencies of these devices tend to be lower than those of less reliable tube devices such as traveling-wave tube amplifiers (TWTAs). This has created the need for the development of efficient solid state power amplifier technology.

Program efforts are being carried out in two areas: first, the development of more efficient solid state amplifier devices, and second, the development of circuits which make more efficient use of these devices. A program has been undertaken with industry to develop more efficient and reliable GaAs field effect transistors operating at X-band. The result has been the development of devices that have power added efficiencies as high as 40% in some cases. Parallel amplifier stages, with their outputs summed in power combiners, are used to obtain the required output power. Efficient field effect transistor (FET) impedance matching and biasing circuits and low loss power combiners have been developed during this effort and testing is now in progress. An engineering model of a 5 watt X-band solid state power amplifier has been developed to meet specifications of the Mariner Mark II Comet Rendezvous/Asteroid Flyby (CRAF) mission (see opposite figure). The amplifier system has demonstrated greater than 30% power added efficiency with 5.5W output power including a dc to dc power regulator with efficiency greater than 85%. Two such systems have been integrated to produce more than 10W and the system has been tested in a vacuum environment. This development has been co-sponsored by OAST and OSSA.

TECHNICAL CONTACT: A.L. Riley, JPL (818) 354-0401

EFFICIENT X-BAND SOLID STATE POWER AMPLIFIER TECHNOLOGY



5.5 WATT X-BAND SOLID STATE AMPLIFIER

Efficient KA-Band Solid State Power Amplifier Technology

The development of efficient spacecraft solid state power amplifier technology for use at Ka-band (32 GHz) is needed to enable improved deep space communications. Ka-band is the next logical band for development beyond the current X-band (8.4 GHz) systems and promises significant telecommunications improvement. In addition, the size and weight of spacecraft components such as antennas, amplifiers and waveguide are reduced.

Efficient power combining and electronic beam steering can be achieved with an active antenna array approach and newly developed millimeter wave monolithic integrated circuits (MMICs) promise to allow low cost implementation. These solid state devices, in addition to their small size and weight, have the potential for higher reliability during extended deep space missions than discrete semiconductor components and the larger and more expensive electron beam devices such as traveling wave tube amplifiers (TWTAs).

An effort is underway at JPL to develop the technology required to construct an efficient 32 GHz active array transmitter system. The approach that has been taken is to evaluate and utilize state of the art Ka-band MMIC devices and to incorporate them into a test bed to evaluate antenna element, signal distribution and control system designs and improve MMIC devices as they become available. Ka-band MMIC amplifiers and phase shifters have been obtained by a cooperative effort with LeRC which developed the devices through industrial contracts. Individual MMICs have been tested at JPL and their performance verified. The initial test bed is a one dimensional phased array (see opposite figure) consisting of various circuit blocks to allow for the insertion of MMIC phase shifters and amplifiers and incorporation of efficient antenna elements and power dividers in a building block fashion. Assembly and test of this unit is now in progress. The goals of this array development include obtaining 20% dc to rf conversion efficiency with 1.5 Watts of millimeter wave output power.

Future plans include the development of more efficient devices, transmit/receive module packages suitable for application in a two dimensional steered array and two dimensional arrays suitable for advanced deep space applications.

This development is jointly sponsored by OAST and OSO.

TECHNICAL CONTACT: A.L. Riley, JPL (818) 354-0401

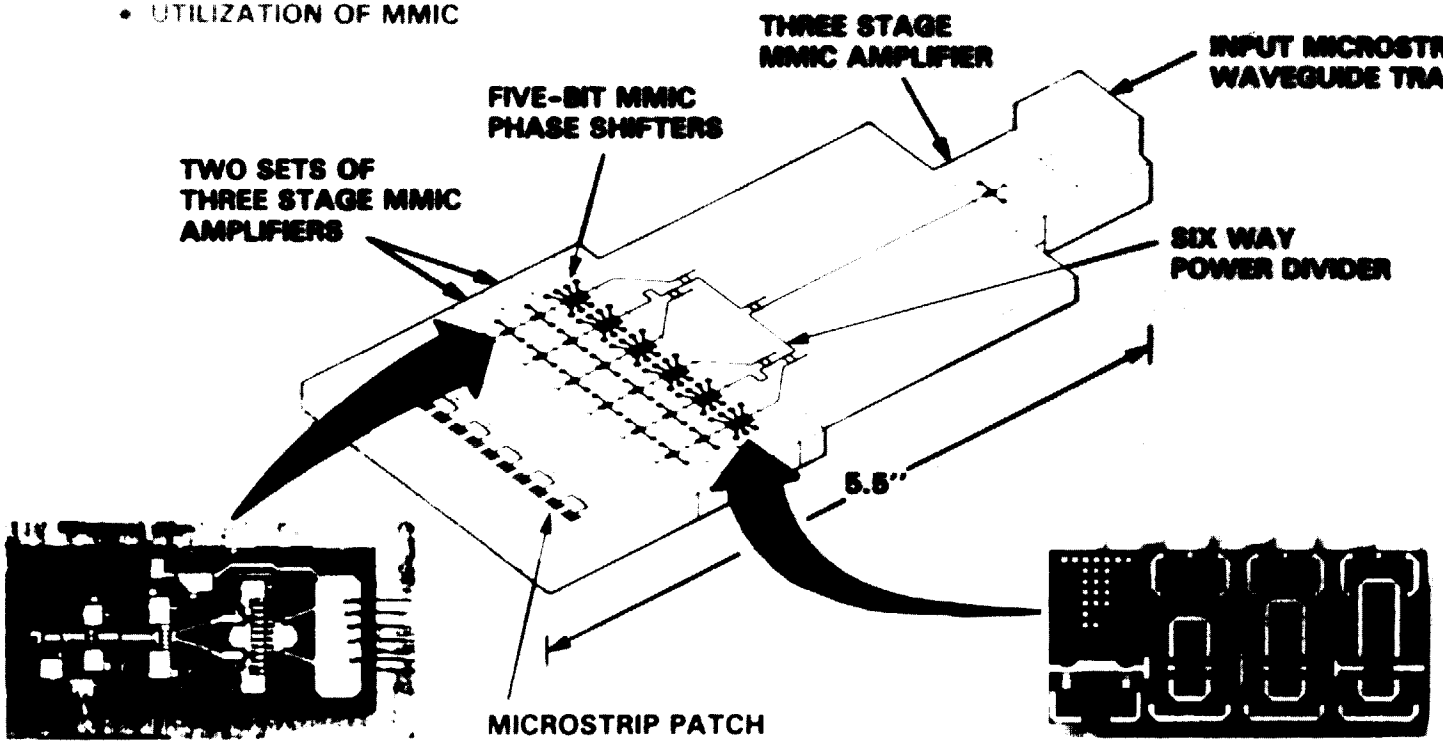
EFFICIENT Ka-BAND SOLID STATE POWER AMPLIFIER TECHNOLOGY

APPROACH:

- ONE DIMENSIONALLY STEERED ACTIVE ARRAY TEST BED
- ALL SOLID STATE
- UTILIZATION OF MMIC

PEFORMANCE GOALS:

- 1.5 W AT 32 GHz
- ± 10° BEAM STEERING



TI THREE STAGE MMIC AMPLIFIERS

HONEYWELL FIVE BIT MMIC PHASE SHIFTERS

Electro-Optical Testing of MMIC Modules

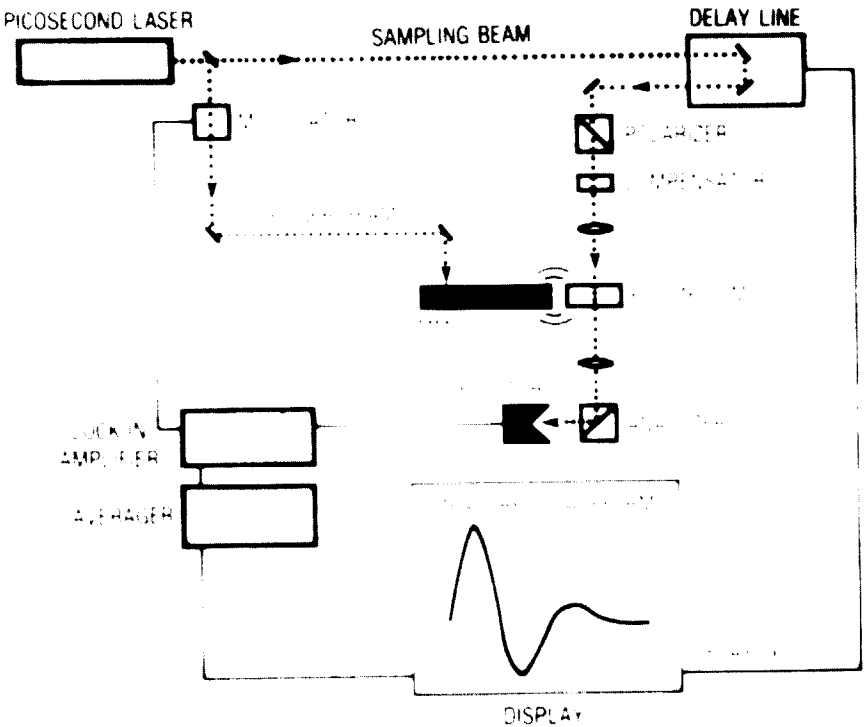
The use of ultra-fast (1 psec) laser pulses for the testing of MMIC modules has the potential of providing a completely no-touch, non-invasive, non-destructive capability. Such testing techniques avoid problems of mounting and wire-bonding, with testing carried out on-wafer, thereby also eliminating the wasteful handling of non-functional chips.

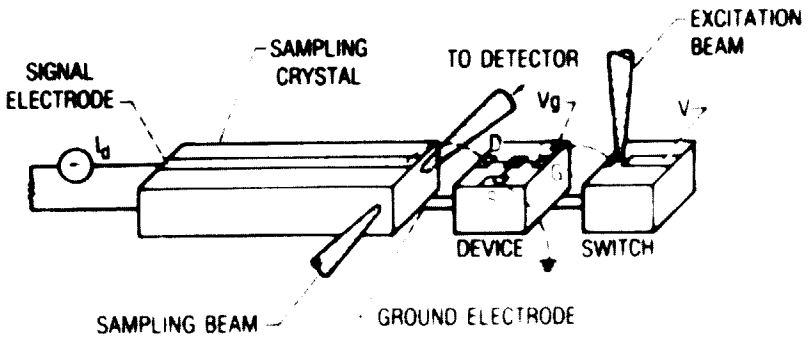
The method provides for direct measurement of S-parameters, and is applicable at frequencies of several hundred Gigahertz. It is adaptable to fully automated, high volume testing with the potential for significantly reducing MMIC costs.

Lewis Research Center has recently carried out preliminary measurements on a 32.5 GHz monolithic amplifier, developed by Texas Instruments under contract. Following fabrication of a "Launcher" and "Analyzer" at LeRC, the unit was tested at the University of Rochester Institute for Laser Energetics, where a picosecond laser is available.

TECHNICAL CONTACT: Kul Bhasin, LeRC (216) 433-3676
Regis Leonard, LeRC (216) 433-3500

TESTING OF MMIC MODULES BY MEANS OF HIGH SPEED OPTICAL SAMPLING





- LeRC MMIC
- UNIVERSITY OF ROCHESTER LASER
- FIRST OPTICAL TESTING OF MMIC MODULE

CD-87-27962

Controls Structure Electromagnetics Interaction Program

The objective is to develop multi-discipline methodology for optimizing RF performance in Large Space Antennas by combining and upgrading discipline technology in the areas of controls, structures, and electromagnetics and to verify this technology through a series of evolutionary experiments using the 15-meter antenna as a generic test article.

The 15-meter antenna tests will be extended to include motorized surface adjustment, adaptive feed electronic compensation techniques, and an integrated discipline code. Testing will begin with a series of experiments to determine the limit of reflector surface smoothness improvement possible using the motorized control and the deployment repeatability of the antenna. Analytical studies will be made with related experiments to determine the accuracy limit of the EAL structural dynamics model already developed for the 15-Meter Hoop/Column antenna.

The surface control system has been designed, parts have been procured, and fabrication of the prototype has been completed. A catwalk for the LaRC building 1293B is being installed so that stereo photography measurements of the antenna can be made during the surface smoothness tests beginning in the fall of 1987. Computations show that the Intelsat feed cluster can electronically compensate the 61 mil surface to a 40 mil equivalent surface. A single Linear Taper Slot Antenna (LTSA) element in an array has been modeled and tested.

Whereas previous researchers have not known the degree of improvement possible using electronic compensation by adaptive feeds, it is now clear that significant equivalent surface smoothness can be achieved.

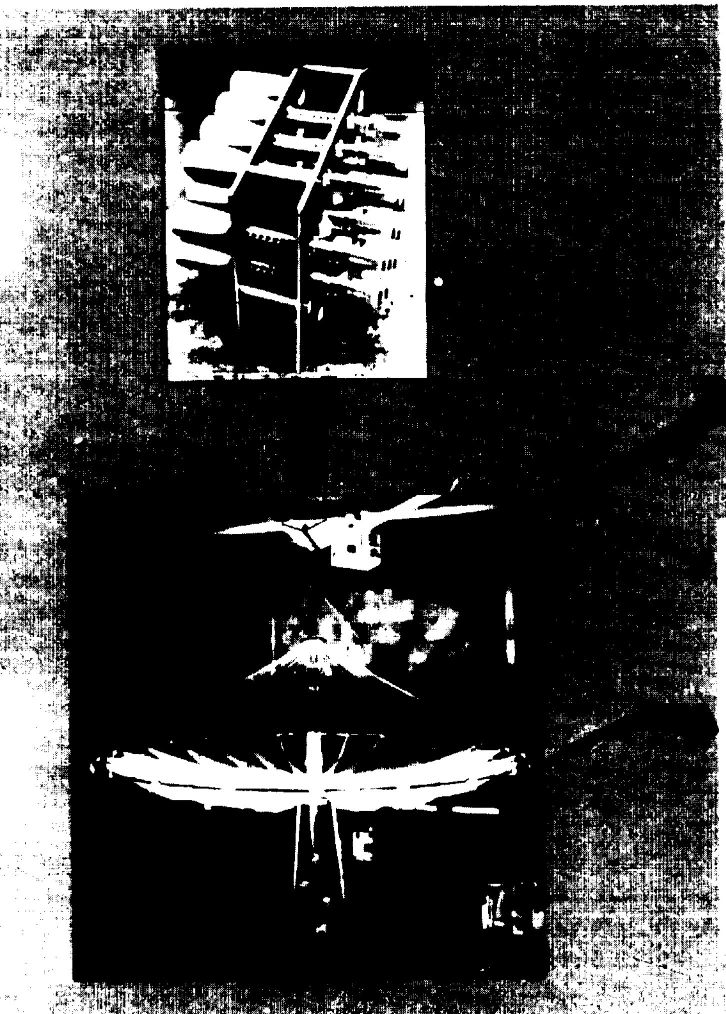
The CSEI Program is a multi-year program with analytical model upgrading in structural dynamics, controls, and electromagnetics. A series of tests with the 15-meter antenna will be conducted with increasing complexity for each test. Ultimately, techniques will be evaluated to optimize antenna RF performance under dynamic condition. Specifically, the surface smoothness tests at LaRC will be followed with electromagnetic testing of the Intelsat adaptive feed at the Denver-Martin Marietta Corp. Near-Field Facility. Later tests are planned to include an advanced feed design and a near-real time optical sensor for dynamic testing of the antenna.

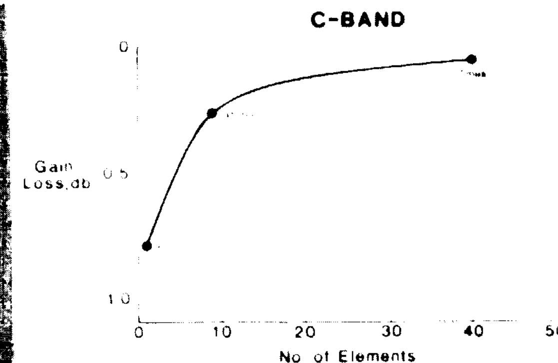
TECHNICAL CONTACT: William L. Grantham, LaRC (804) 865-3631

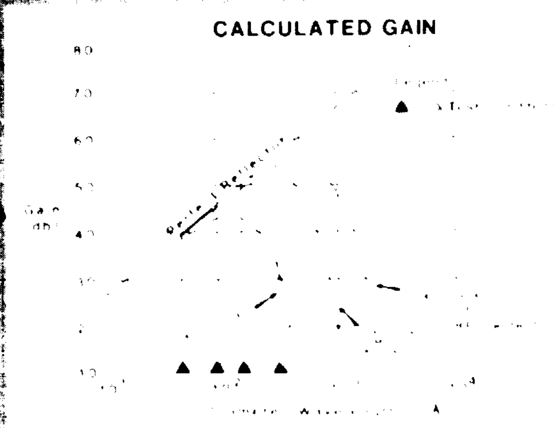
CSEI
RF PERFORMANCE OPTIMIZATION

Electronic Compensation Study

Surface Adjustments Design







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Reflector Distortion Analysis and Compensation

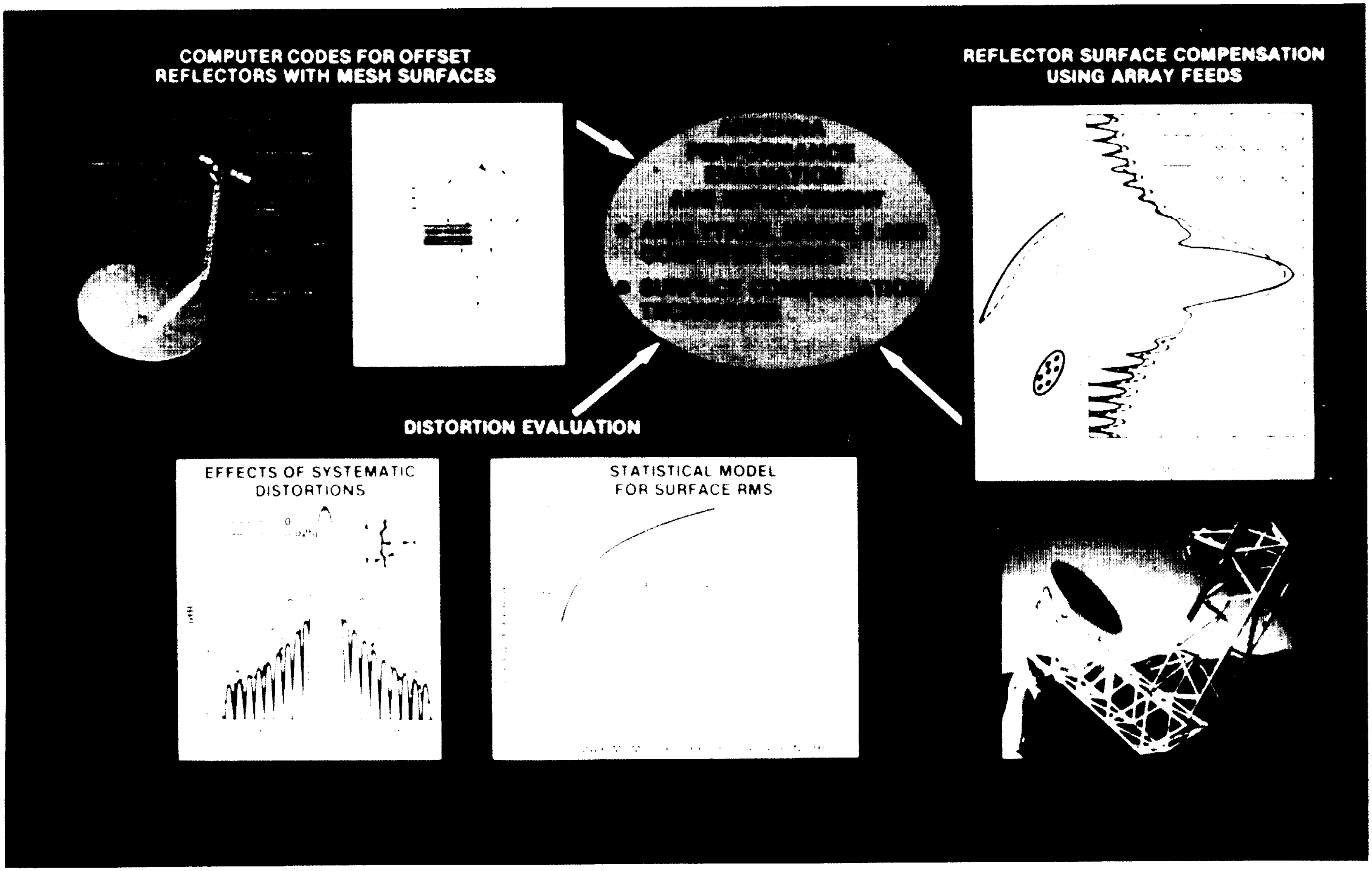
Future satellite communications and scientific missions will utilize large deployable reflector antennas with stringent gain and sidelobe requirements. As an example, in the upper left corner is shown an artist's rendition of the second generation mobile satellite antenna which may utilize a 20-meter mesh reflector antenna. The performance of these reflectors can be degraded by surface distortions caused by variety of sources including thermal, dynamical changes and other effects. It is highly desirable to be able to analyze the effects of these systematic and random distortions and then to compensate for their effects in order to maintain the required system performance subject to these unwanted circumstances.

A generalized computer algorithm has been developed, with its steps depicted in the upper left corner, which allows an accurate diffraction analysis of reflectors subject to systematic distortions including the mesh surface effects. In the lower left corner is shown a typical diffraction analysis for a reflector with a periodic systematic surface distortion. It can be observed that these types of distortions can result in an unwanted sidelobe degradation. Also shown is the result of a newly developed statistical model for the prediction of the effects of the surface rms in the degradation of the sidelobe levels for specified values of the expected probability of the occurrence. These kinds of results can be of great use to the antenna designer in selecting appropriate surface models in maintaining the required overall system performance.

A novel technique based on the application of the conjugate field match concept has been developed for the purpose of distortion compensation. A generalized computer program has been developed which automatically generates the desired feed element's complex (amplitude and phase) excitation coefficients and then produces the compensated far-field pattern. In order to apply the surface compensation algorithm it must be assumed that the surface distortion profile is known. This knowledge can be provided either in terms of a functional description or in terms of discrete points. The surface distortion profile can be obtained by using optical, microwave holographic, photogrammetric techniques. Additionally, one might be able to use an adaptive procedure to directly measure the required excitation coefficients of the array which can become very useful for in-space compensation of reflector distortions. Based on many simulations, it has been found the concept can be very effective in overcoming the effects of slowly varying distortions by utilizing arrays with a small number of elements. In the upper right corner are shown the results of such a computer simulation to demonstrate how the distorted pattern (shown in red) can be improved by utilizing a 16 element array feed as shown by the black curve. Currently an experiment is being conducted (lower right corner) to verify the accuracy of the computer predicted performance and the results so far are very favorable.

TECHNICAL CONTACT: Dr. Y. Rahmat-Samii, JPL (818) 354-5714

REFLECTOR DISTORTION ANALYSIS AND COMPENSATION



High Power Laser Diodes for Space Communication Systems

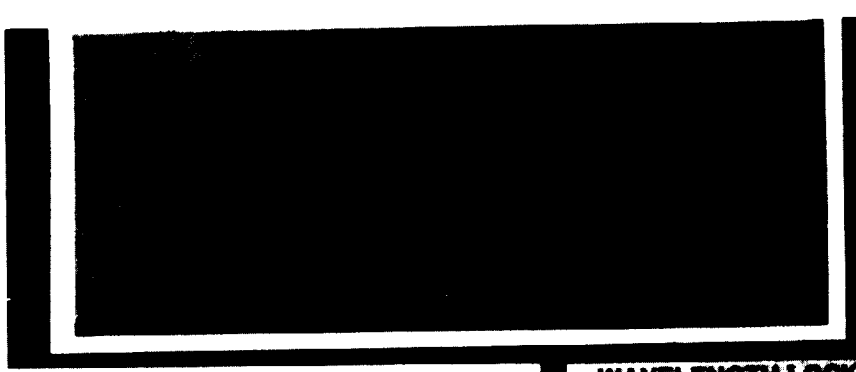
Laser systems are attractive for satellite communications systems because they are small, all solid state, and are capable of carrying data rates in excess of 200 Mbits/sec. NASA is developing laser systems which transmit data between satellites by directly modulating the output powers of semiconductor lasers with injected current. Although powers in excess of 100 mW are required to carry NASA data rates, the best commercially available semiconductor lasers are limited to powers less than 40 mW.

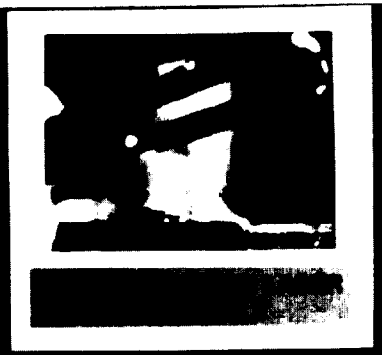
OAST has undertaken the development of high-power diffraction-limited AlGaAs lasers at the David Sarnoff Research Center in order to improve laser performance. Recent work on the Channeled-Substrate Planar (CSP) structure has improved its electrical efficiency, has yielded less than 1/30th wave phase-front error, and has demonstrated over 5000 hours lifetime at 50 mW output power. These improvements did not impact the 100 mW peak power capability of the lasers or the 300 psec rise and fall times of the device, which permit 1 Gbit/sec data rates.

A distributed-feedback (DFB) structure has also been successfully demonstrated in the AlGaAs CSP laser by David Sarnoff Research Center. This structure is a diffraction grating grown directly into the laser. It forces the laser to operate in a single optical frequency, even under the conditions of high-depth high-speed modulation. Such DFB-CSP lasers are ideal for use in power combiner systems, such as those built by OSSA. They permit much tighter wavelength spacing in the power combiners, which allows much higher data rate systems. The development of arrays of DFB lasers should allow the transmitter subsystems to be reduced in size and weight. Due to these payoffs, NASA's progress in improving high power AlGaAs lasers continues to advance free-space laser communications technology.

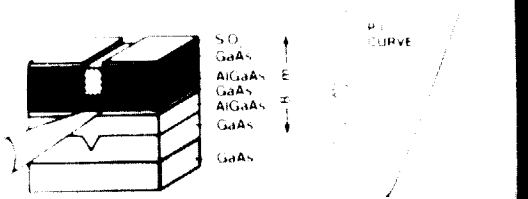
TECHNICAL CONTACT: Jim Abshire, GSFC (301) 286-8948

OAST DEVELOPED HIGH POWER LASER DIODES FOR SPACE COMMUNICATIONS



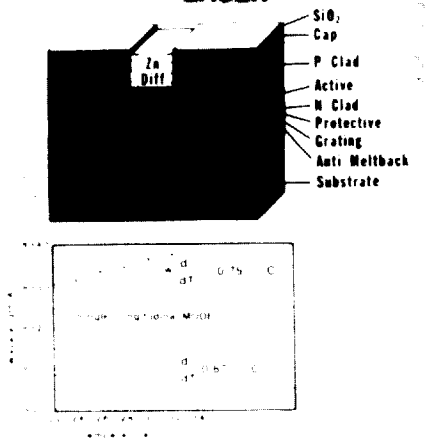


INDEX-GUIDED CSP LASER



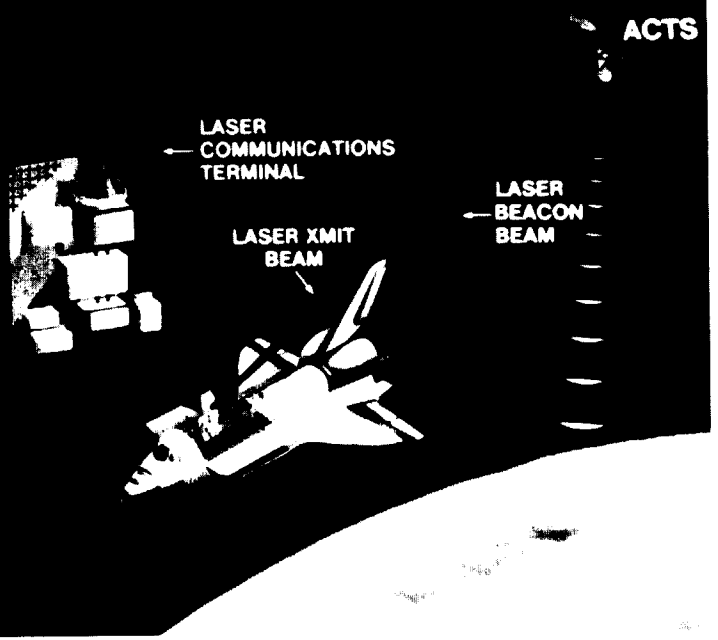
100mW cw
Phased Front Error /30

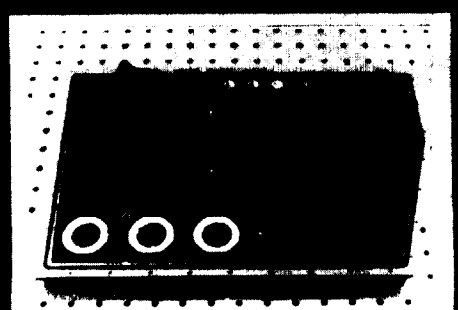
WAVELENGTH LOCKED DFB-CSP LASER



PAYOFFS

- Lighter Systems
- Higher Reliability Transmitter
- Closely Spaced Wavelength Division Multiplexing





OSSA LASER DIODE TRANSMITTER SUBSYSTEM

High Efficiency Lasers

Many laser applications require high peak power laser output pulses with high overall power conversion efficiency. Lasing has recently been demonstrated in a holmium doped yttrium lithium fluoride (Ho:YLF) crystal when pumped by a semiconductor laser array. The crystal, which lases at 2.06 um, has a fluorescence lifetime 60 times longer than the familiar Nd:YAG, thereby permitting much higher peak power buildup. 30 mW of continuous-wave output power has been achieved to date with an optical pump to optical output conversion efficiency near 20%. Cooling of the crystal to 77K is currently done to permit efficient lasing.

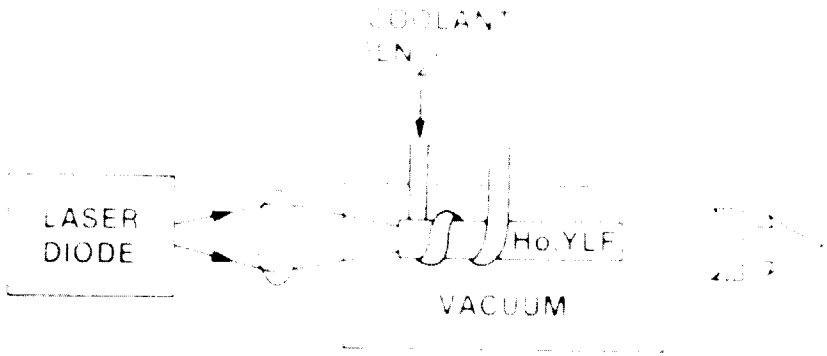
The applications for such lasers are: Free Space Optical Communications, Optical Fiber Communication, Medical Instrumentation and Remote Sensing.

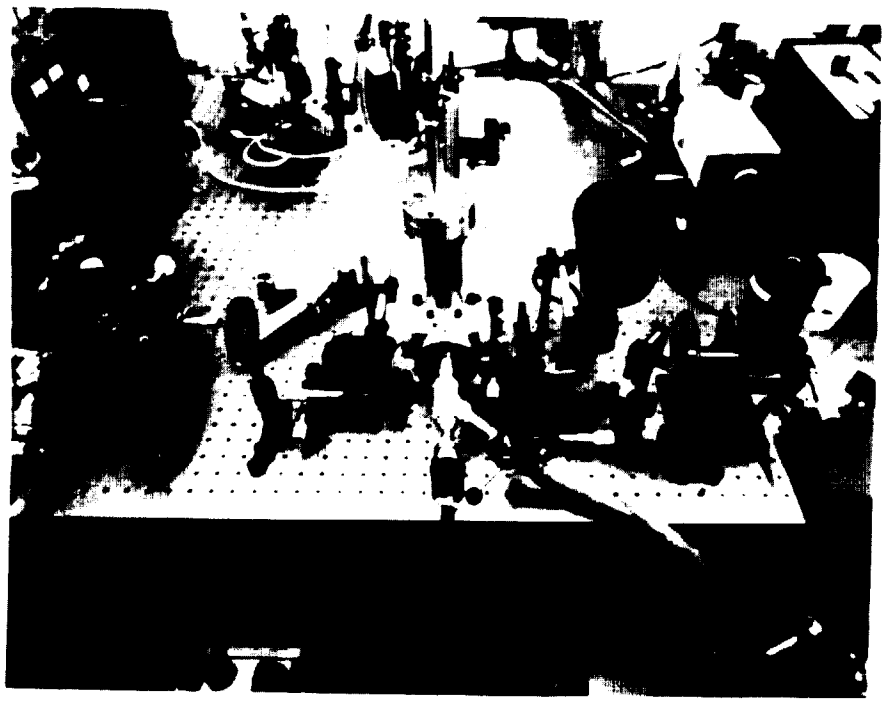
TECHNICAL CONTACT: James R. Lesh, JPL (818) 354-2766

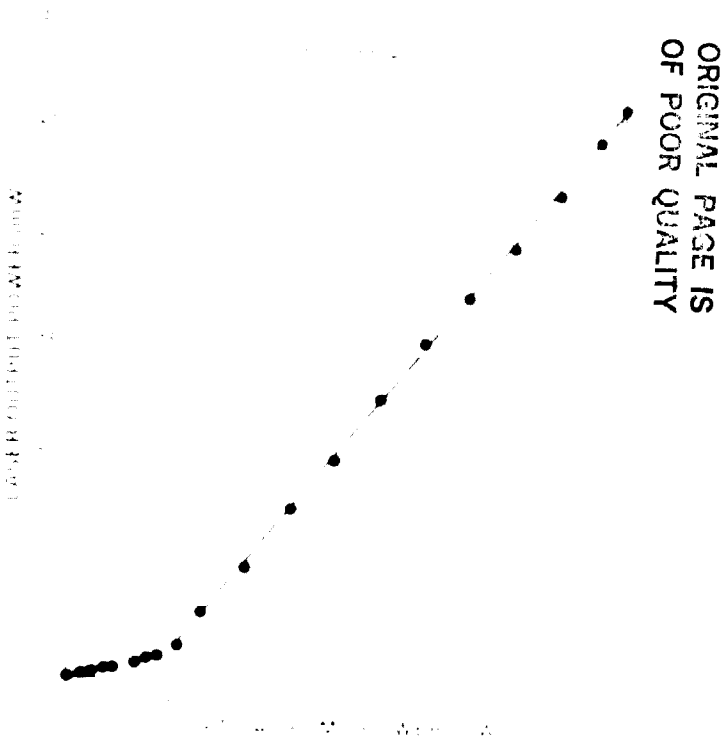
JPL

HIGH EFFICIENCY LASERS
506-00-00

- DESIGNED LASER USING YTTRIUM LITHIUM FLUORIDE DOPED WITH HOLMIUM AS LASING CRYSTAL (Ho:YLF)
- USES DIODE LASERS AS PUMP
- ACHIEVED 25 mW OUTPUT POWER







Integrated Optical Communication Test Bench

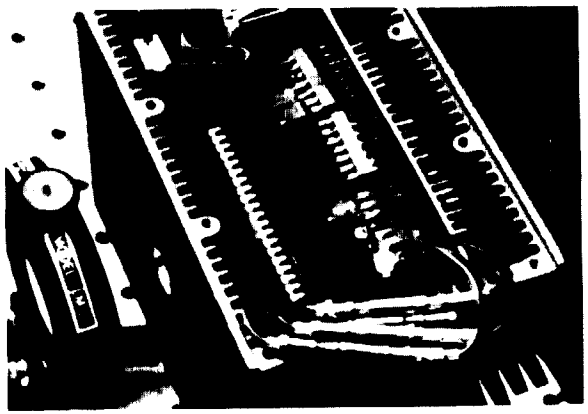
The Integrated Optical Communication Test Bench (IOCTB) has been designed to provide a test bed for subsystem level evaluation of performances and design constraints for optical communication technology elements such as laser transmitters, modulators, tracking detectors, and high-gain data detectors. The first task is to test the capabilities of the 128x128 pixel Random Access Charge Injection Device (RACID) detector array. This device should provide a capability for the rapid acquisition of uplink beacon sources, thereby providing a pointing reference for the data return beam. This array detector will also provide high-bandwidth spatial tracking information to compensate for spacecraft body vibrational modes. The test bench will be used to evaluate this acquisition and tracking detector array under spatial image intensity variations and quantization effects typical of planetary optical communication channels.

TECHNICAL CONTACT: Dr. James R. Lesh, JPL (818) 354-2766

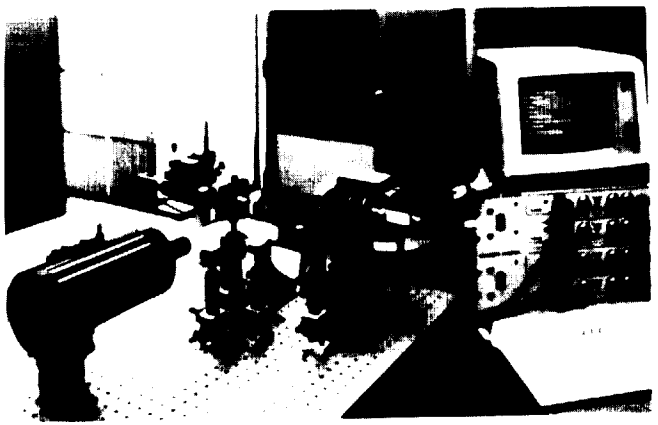
JPL

INTEGRATED OPTICAL COMMUNICATION TEST BENCH
506-44-21

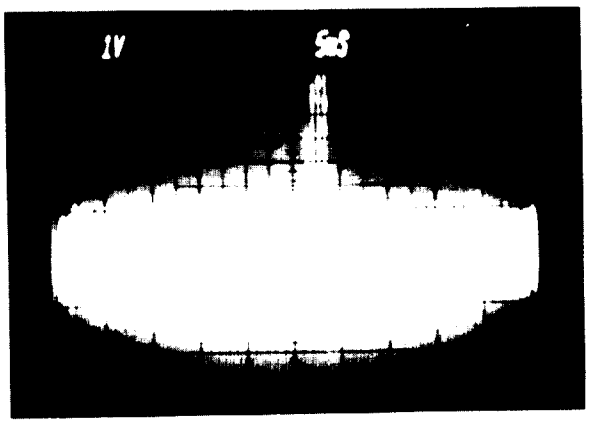
- DESIGNED FLEXIBLE TEST BED FOR OPTICAL COMMUNICATION TECHNOLOGIES
- USES 128x128 RANDOM ACCESS CID IMAGER FOR ACQUISITION AND TRACKING
- DICHROIC BEAMSPLITTERS PERMIT TRANSMIT AND RECEIVE PATH ISOLATION
- ELECTRONICS AND CONTROL ALGORITHMS ARE GENERAL PURPOSE AND IN RACK MOUNTED CHASSIS



CHARGE INJECTION DEVICE HOUSING



INTEGRATED OPTICAL COMMUNICATION TEST BENCH



OSCILLOSCOPE TRACE OF CID OUTPUT OF A LASER BEAM IMAGED ONTO THE CHARGE INJECTION DEVICE

Computer Sciences

The Computer Science Program provides advanced concepts, techniques, system architectures, algorithms and software for both space and aeronautics information sciences and computer systems.

The overall goal of the Computer Science Research Program is to provide the technical foundation within NASA for the advancement of computing technology in aerospace applications. This goal will be realized through a program of basic research and experimentation which focuses on developing core skills within the Agency in disciplines critical to NASA and on maintaining a strong university base of fundamental research in aerospace computer science.

The research program is improving the state of knowledge of fundamental aerospace computing principles and advancing computing technology in space applications such as software engineering and information extraction from data collected by scientific instruments in space. Emphasis is being placed on producing highly reliable software for critical space applications.

The program includes the development of special algorithms and techniques to exploit the computing power provided by high performance parallel processors and special purpose architectures. Problem areas of importance include computational fluid dynamics, computational chemistry, structural analysis, signal processing and image processing. The computer architectures of interest include common and local memory multiprocessors, single-instruction stream multiple data stream processors, static data flow processors, systolic arrays and heterogeneous multiprocessors with custom processors. Research is conducted in programming languages and environments, parallel and distributed operating systems and performance measurements.

Research is being conducted in the fundamentals of data base logic. This work has resulted in the development of a common user interface for accessing data from several data bases even when the data bases being accessed have very different structures. This work provides the foundation that will enable NASA space data users access to multiple data bases independent of their physical distribution or structure. This work will reduce the cost of such investigations and enable data base intensive scientific research that would otherwise be unaffordable. Other work is underway to develop and test an expert system that can serve as an assistant to researchers analyzing space derived data.

Research is being conducted to improve techniques for producing reliable computing systems. That work is directed at both reducing the number of faults in software and making systems that are tolerant to faults. New approaches and methods for software management and engineering have been devised and are now being evaluated under real working conditions. Future objectives in a new software engineering initiative will include research on the theoretical foundation, and extending and evaluating approaches for developing reliable complex software.

The Computer Sciences Program is coordinated with the Space Station's Software Support Environment (SSE) and the DOD sponsored Software Engineering Institute (SEI) and ADA. NASA also participates with DOD on several advisory and technical committees.

PROGRAM MANAGER: Dr. Paul H. Smith
NASA/OAST/RC
Washington, DC 20546
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Advanced Computer Science At RIACS: Reaching for Tomorrow's Scientific Computing

RIACS was established at the Ames Research Center in June 1983. It is privately operated by the Universities Space Research Association (USRA) under a cooperative agreement with NASA. Its purposes are to help build a pool of top computer science talent at Ames, to conduct a research program, to attract top computer science faculty and industrial researchers on leave, and to establish links with universities and industry. Its core research objective is high level computational support of the entire process of scientific investigation, from formulation of problem statements to dissemination of the results. The RIACS research program has four major project areas; Advanced Algorithms and Architectures, Sparse Distributed Memory, Telescience, and Scientist's Workbench.

Advanced Algorithms and Architectures. We are studying the abilities of novel computing architectures controlled by new algorithms to provide significant increases in computing power for disciplines of interest to NASA, notably fluid dynamics and chemistry. These studies also include the design of new architectures specially tailored for important classes of problems, such as particle simulations of fluids, plasmas, and galactic formations. Working with DARPA and NASA, RIACS proposes to create a Center for Advanced Architectures (CAA), a facility that will permit deep testing of new architectures in many disciplines. The initial machine would be a Connection Machine 2, which has 16,000 processors and floating-point capability.

Sparse Distributed Memory. We are studying the theory and implementation of a new architecture that can store and retrieve long binary vectors (e.g., 1000 bits) representing encoded moments of experience. Retrieval requires only that the cue vector match a stored vector in enough bits. This architecture holds great promise for pattern problems in speech reccgnition, vision, robotics, and space automation.

Telescience. We are studying the architecture of a worldwide distributed computing environment capable of supporting the conduct of scientific research. This includes remote operation of instruments, remote collaboration, and remote use of computational resources around the network. A consortium of 15 universities is working with us to conduct experiments in their disciplines so that we can determine the requirements created by real users.

Scientist's Workbench. We are studying the functions needed in the workstation on a scientist's desk for maximal effectiveness in research. These include tools for program preparation, editing, remote use of supercomputers and databases, report preparation, visual composition of distributed programs, mathematical support tools, interfaces tailored to the discipline, and interactive graphics. Computational chemists are testing the facility as it is developed.

TECHNICAL CONTACT: Peter J. Denning, ARC (415) 694-6363

ADVANCED COMPUTER SCIENCE AT RIACS

Research Goal:
Computational Support for Entire Process
of Scientific Investigation

Need to use new technologies effectively

Parallel Architectures

- ▪ Sequent Balance 21000
- ▪ Intel iPSC & N-Cube
- ▪ Connection Machine CM2
- ▪ Convex C1
- ▲ FPS-T
- ▲ Data Flow Machine
- ▲ Saxpy-1M
- ✡ Ultra Computer (IBM)
- ✡ Navier-Stokes Machine
- ✡ Particle simulators

Wide Area Distributed Computing

Workstations
Supercomputers
Vendor independent local nets
National Research Internet
Shared programs, data, services
Telescience
Seamless computing environment

ICASE Computer Science Research

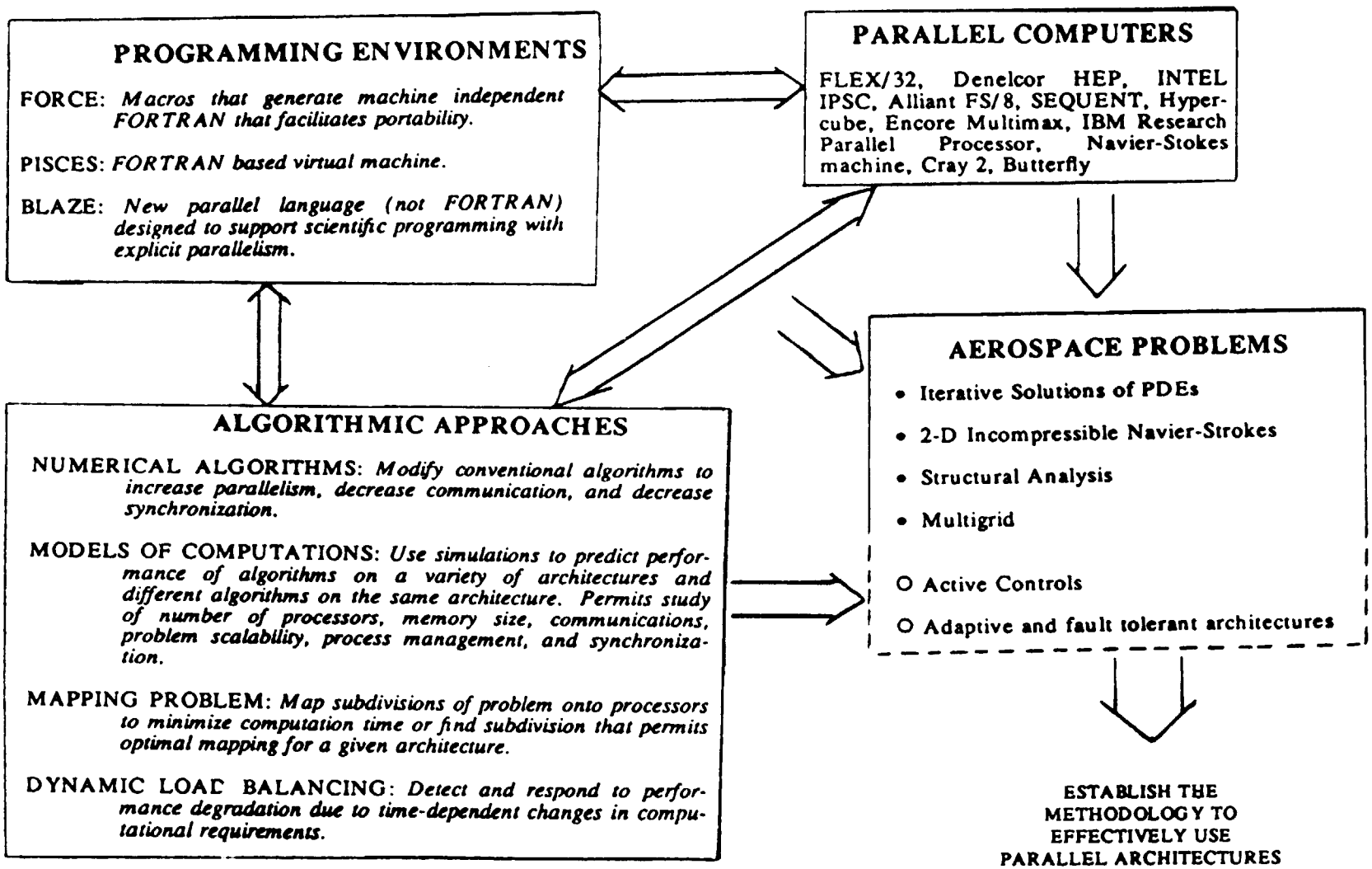
Computer science research at ICASE is focused on developing the methodology required to utilize parallel computing systems effectively for complex aerospace problems. Historically, computational requirements for problems such as the simulation of three dimensional fluid dynamics phenomena have exceeded the performance of available systems and it is now clear that significant increases in that performance will require parallel systems.

Central to the ICASE research program is the recognition that parallel computing is a systems issue involving the interaction of architecture, operating systems where problems such as synchronization and load balancing appear, programming environments including languages and tools, and numerical algorithms. Projects exist in all of these areas. For example, programming environments known as the Force, PISCES and BLAZE have been developed and implemented on a variety of machines. Research is now underway to determine the effectiveness of these approaches in terms of programmer efficiency and performance. Portability of algorithms between different architectures is also being studied using the environments. Many have taken the position that portability will extract a high price in terms of performance but there is no data to substantiate the claim or to quantify the penalty.

The design space of potential parallel architectures is very rich. In order to evaluate various alternatives, models of computation are being developed that include the usual computational complexity as well as system overhead such as synchronization and communication costs. The goal is to develop these models for non-trivial applications, not just simple arithmetic kernels. The models are validated using measured performance obtained from a variety of operational parallel systems. Such studies identify the best match between the problem of interest and architectural parameters such as number of processors, floating point computation rate, communication topology and memory size.

TECHNICAL CONTACT: Bob Voigt, LaRC (804) 865-2513

ICASE COMPUTER SCIENCE RESEARCH



Illinois Computing Laboratory for Aerospace Systems and Software

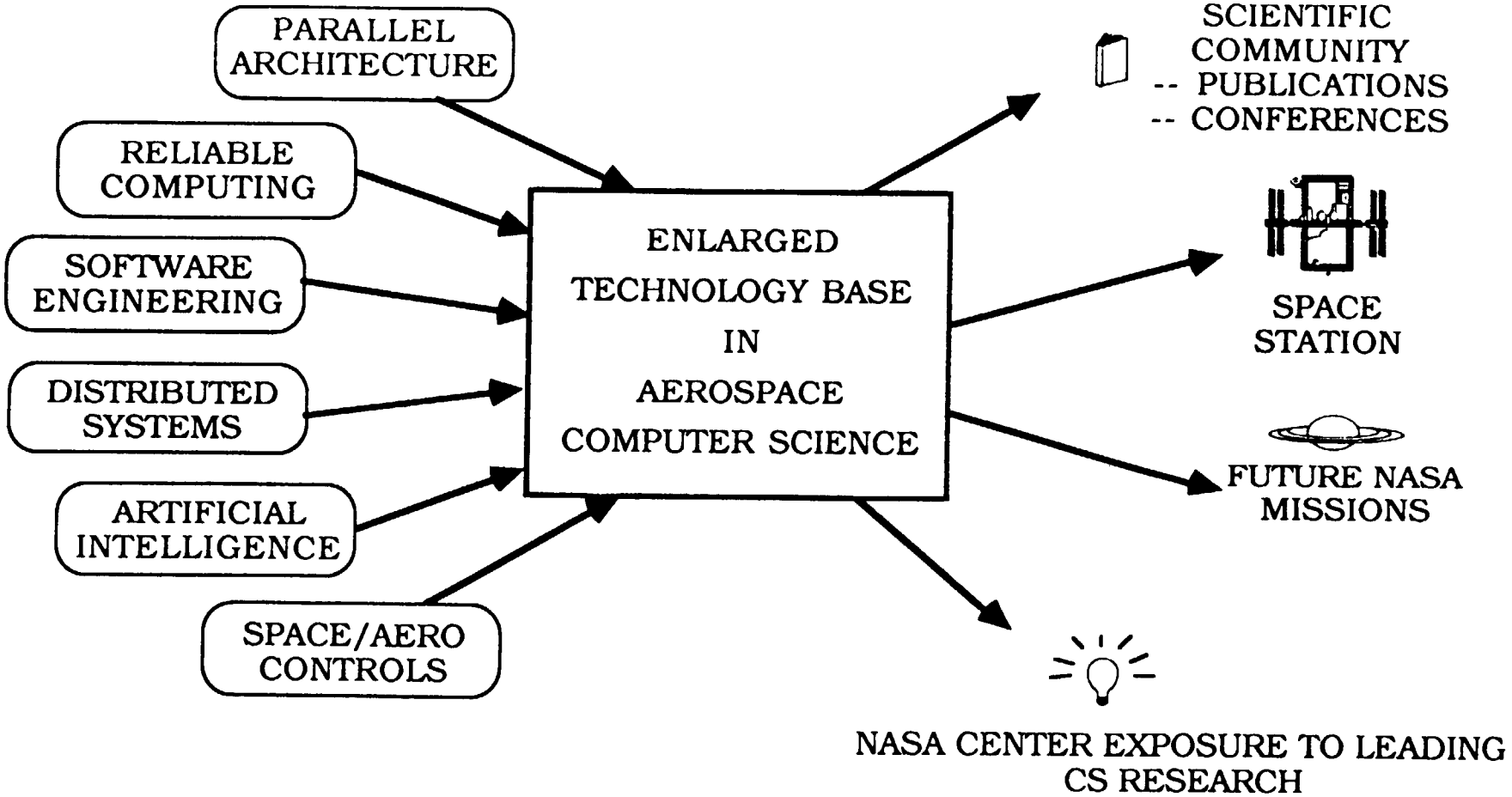
Focusing the attention of leading researchers in computer science and engineering on problems of interest to NASA is the primary goal of the center of excellence at the University of Illinois at Urbana-Champaign. The center, called the Illinois Computing Laboratory for Aerospace Systems and Software (ICLASS), involves over 15 graduate students and their faculty advisors in the departments of Computer Science, Electrical and Computer Engineering, and Aeronautics and Astronautics. ICLASS was established in 1985 under the OAST computer science program and has research activities in the areas of parallel architectures and algorithms, reliable and fault-tolerant computing, software engineering, distributed and real-time systems, artificial intelligence, and real-time computation in aircraft and spacecraft control maneuvers.

During the annual review for NASA in November 1987, the faculty and students reported on 21 research tasks, ranging from multicomputer system software and real-time scheduling in distributed systems to fault tolerant parallel architectures and architectures for image understanding. Some highlights of the past year include: completion of a trace analysis facility to study memory referencing and allocation policies for main and local memory in a parallel computing architecture; development of a parallel algorithm for VLSI design of cell placement; a methodology to evaluate LISP architectures; a strategy for error detection and recovery in large grain applicative/functional parallel architectures; an approach for reconfigurable massively parallel tree architectures; simulation of the JPL HyperSwitch design; implementation of a virtual macro data flow system on a 10-processor Encore Multimax system; a software architecture allowing an application to run on heterogeneous processors(e.g., workstation and supercomputer) using a virtual address space; a system for abstract, executable specifications of C++ classes; and development of an efficient class of geometrical data structures, called information trees, for texture discrimination and image segmentation.

The synergism resulting from the variety of research interest areas among the ICLASS participants and the interaction with NASA researchers in computer science has greatly enhanced and stimulated the Agency research program. Several faculty members have visited various NASA Centers and provided advice on computing issues. During the summer of 1987, four students spent extended work periods at Langley and Ames Research Centers.

TECHNICAL CONTACT: Susan J. Voigt, LaRC (804) 865-3535

ICLASS
ILLINOIS COMPUTING LABORATORY FOR AEROSPACE SYSTEMS



-- FOCUS ATTENTION OF CS RESEARCHERS ON NASA - RELATED PROBLEMS
-- INVOLVE GRADUATE STUDENTS AND RESEARCH FACULTY
-- ENHANCE NASA COMPUTER SCIENCE UNDERSTANDING
-- LARC COORDINATES AND MAINTAINS CLOSE TECHNICAL COMMUNICATION

Distributed Access View Integrated Database (DAVID)

The objective of the DAVID project is the development of computer software that will enable NASA scientists to uniformly access datasets and programs independent of the computer on which they are located, the operating system of the computer, the network on which the computer resides. Functionally, DAVID will be a heterogeneous distributed database management system, a homogeneous distributed database management system, a heterogeneous distributed operating system, and a heterogeneous distributed communications system.

This year's accomplishments have occurred in three parts.

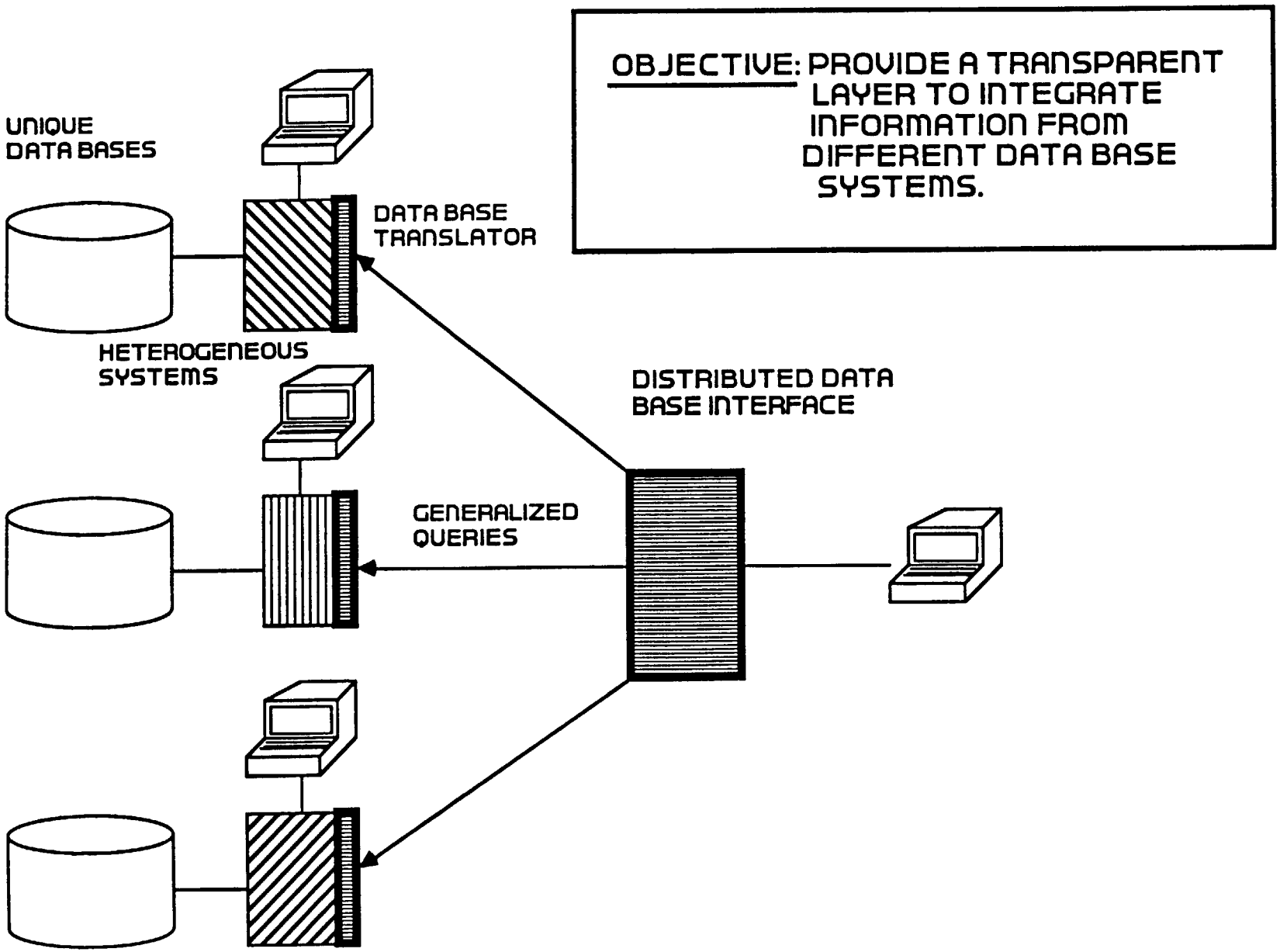
First, building and testing of the basic DAVID software were completed for many of the DAVID modules. Some of this (C language) software runs on each of the computers partaking in the DAVID system: DAVID Generalized SQL Primitives, Host Language Interface, Generic Cluster Access and File Access. Another portion of software runs primarily on an AT&T 3B/2 (designated as the "DAVID Machine") and coordinates DAVID processing on each local area network: Terminal Interface, Generalized SQL Translation Package, Constraint Realization, View Integration Package, Scheduler, Installation and Backup.

Second, building and testing interfaces between the DAVID system and underlying databases and database management systems were completed. Some of these included some astrophysical source catalogues as well as ORACLE and INGRES database management systems. Each dataset requires a corresponding DAVID definition together with fetch, insert, delete and update commands. When interfacing a database management system, (e.g., ORACLE) one interface will work for all the databases in the management system.

Finally, design and detailed software specifications for a "library layer" on top of the DAVID system was completed. In the design, each local area network becomes logically viewed as a "library". Components such as citation systems, local and union catalogues enable the user to isolate desired datasets, locate which "library" possesses it, and where in the particular "library" the dataset can be found.

TECHNICAL CONTACT: Barry E. Jacobs, GSFC (301) 286-5661

DISTRIBUTED ACCESS VIEW INTEGRATED DATA BASE



Intelligent Data Management Processes

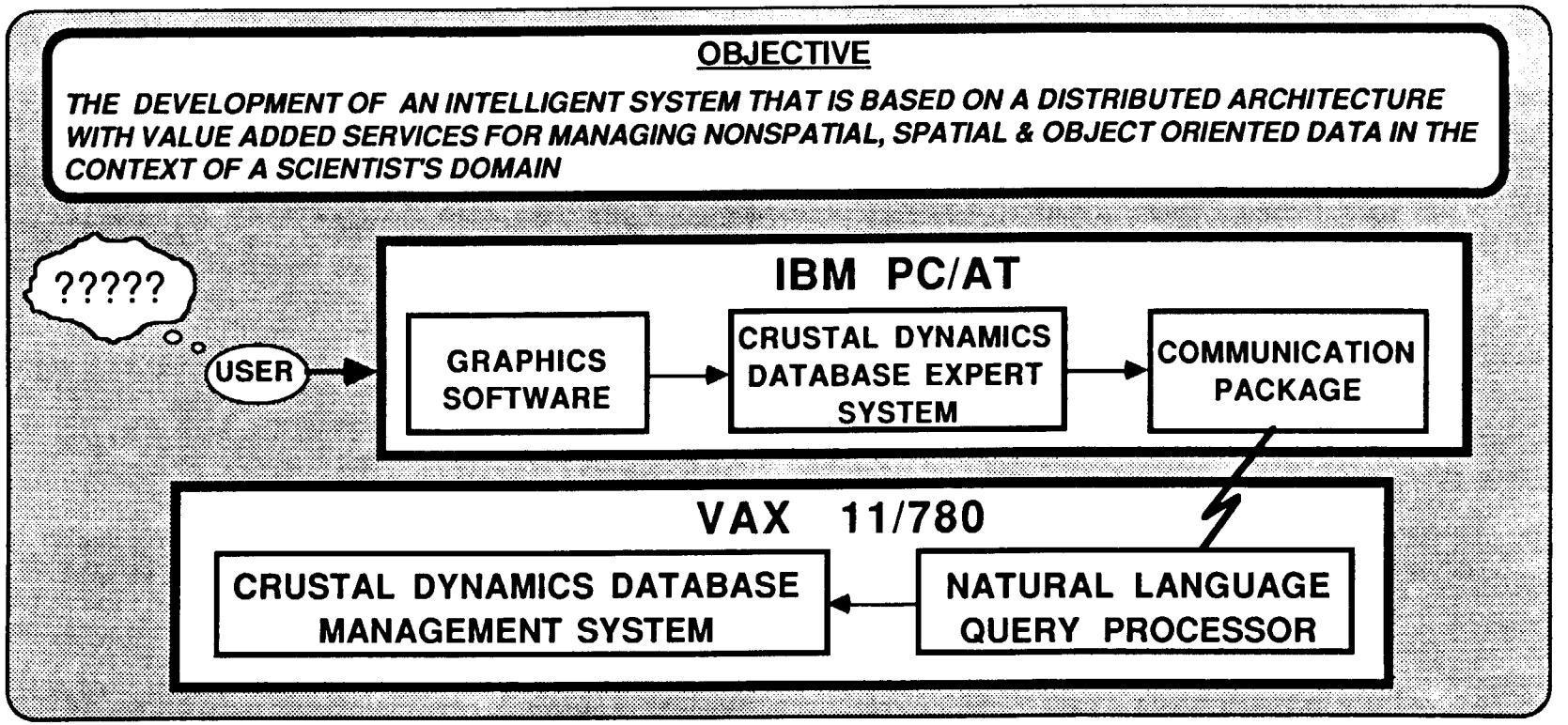
The objective of the Intelligent Data Management project is the development of an intelligent system that is based on a distributed architecture with value added services for managing non-spatial, spatial, and object oriented data in the context of a scientist's domain. These scientists have a need for on-line access to space and earth related data, but may not have the needed experience in database operations and procedures. The long term research goals are: 1) development of intelligent value-added services that will enable scientists to interact with the most complex database systems with minimal understanding of the system architecture, stored data, or query language; 2) development of automatic data cataloging and characterization with minimal user guidance and interaction; and 3) management of non-spatial, spatial, and object oriented data in the same operating environment.

A first generation prototype Intelligent User Interface (IUI) has been developed that provides the capability for a scientist to casually browse a remote operational scientific database with no previous training or experience using plain English or graphically. This system was implemented on an IBM PC/AT using an expert system development tool. The natural language query processor parses the English query into the database management system language which is remotely located and processes and returns the desired information back to the scientist over a communication network. All software is commercially available.

Coding has begun for the next generation data management system on a LISP machine and a powerful 32-bit microcomputer using advanced expert system shells and 3-D graphics. The integrated environment of these tools provides the mechanism for imbedding knowledge and domain expertise in the data structures themselves (i.e., frame-based, quad-trees, etc.), thereby providing for the first time, a truly generic and robust data management system to rapidly search, access, manipulate, and display specific data relevant to a scientist.

TECHNICAL CONTACT: William J. Campbell, GSFC (301) 286-8785

INTELLIGENT DATA MANAGEMENT / USER INTERFACE SUBSYSTEM



POTENTIAL USERS

- SPACE STATION/SAIS
- EOS
- SPACE TELESCOPE
- EXISTING NASA DATA SYSTEMS

ACCOMPLISHMENTS

PROTOTYPED PHASE ONE IUI INCLUDING:

- KNOWLEDGE-BASED MANAGEMENT CONTROLLER
- NATURAL LANGUAGE QUERY PROCESSOR (NLQP)
- EXPERT SYSTEMS GRAPHIC INTERFACE

DEMONSTRATED PROTOTYPE WITH AN OPERATIONAL DBMS

113log340a

Knowledge-Based Expert System for Hyperspectral Image Analysis (SPECTRUM)

The goal of this project is to develop an intelligent data analysis environment for imaging spectrometer data, with an emphasis on analysis in the context of Geology. Additional objectives include the development of new techniques for the combination of symbolic and numerical processing and the investigation of shared control or "mixed-initiative" expert system interfaces, in which the user and system collectively manage the ongoing analysis.

The hyperspectral image analysis expert system (SPECTRUM) is implemented using a combination of programming languages STAR and C. STAR was developed in the early stages of this task explicitly for the construction of hybrid/symbolic numerical Artificial Intelligence applications such as SPECTRUM. Source code for STAR was submitted to NASA's COSMIC facility, and the language has been described in three publications. Organization of the SPECTRUM system centers around the Incremental Inference algorithm, a symbolic reasoning mechanism designed to support "mixed-initiative" control of expert systems. SPECTRUM accepts varying degrees of input from its user, complementing this with control knowledge maintained by the system. This operation ranges from manual to automatic based on the behavior of the user.

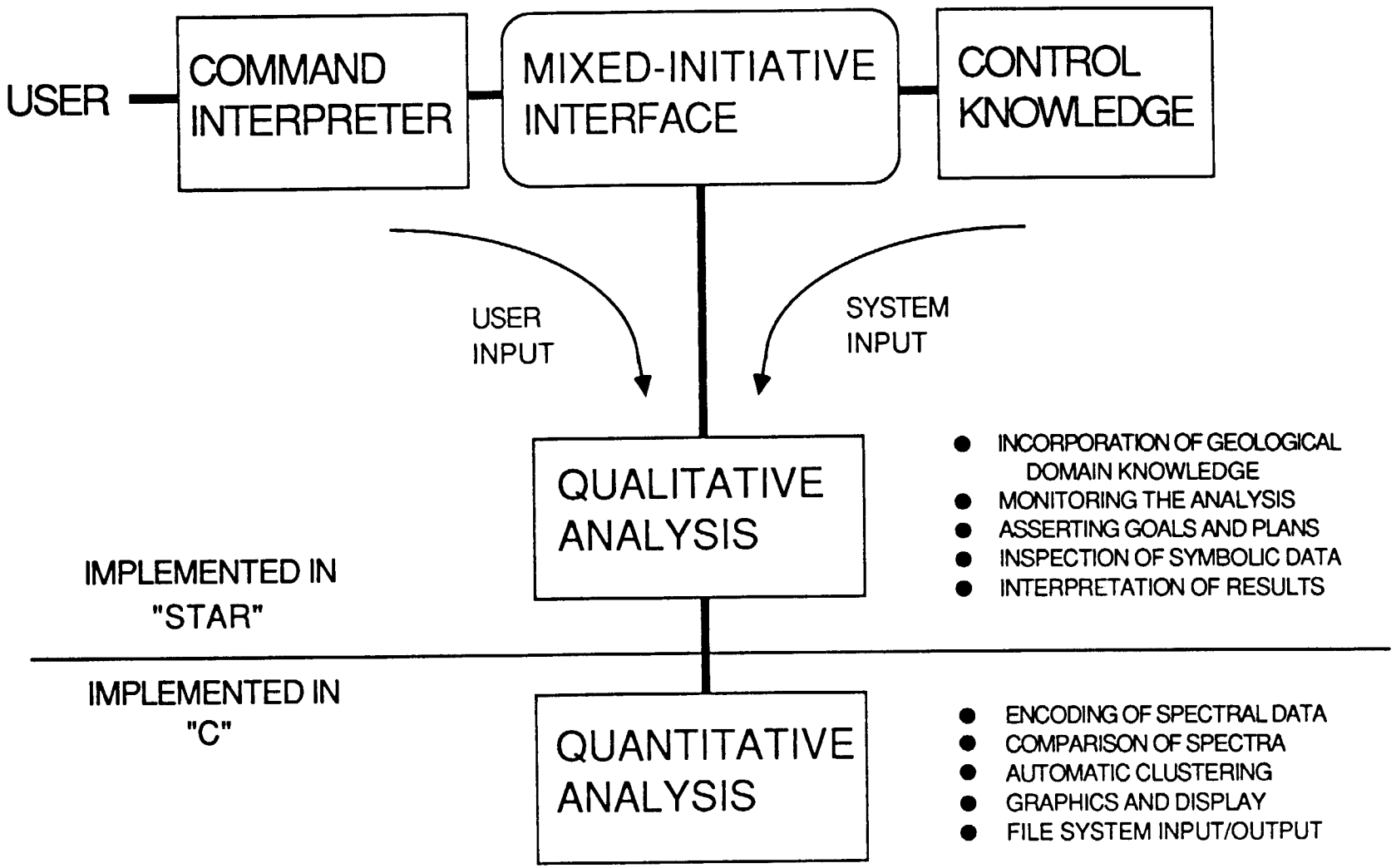
During FY87, refinements to the prototype version of SPECTRUM were completed, providing extended analysis capabilities and supporting the mixed-initiative control environment for the system. Progress on SPECTRUM was described at the IEEE Computer Society 15th Workshop on Applied Imagery Pattern Recognition, October, 1986 in Washington, DC and at the AAAI 2nd Workshop on Coupling Symbolic and Numeric Computing in Knowledge-Based Systems, July, 1987 in Bellevue, WA. The Incremental Inference algorithm has been presented at the NASA /Space Telerobotics Workshop, January, 1987 in Pasadena, CA and at the AAAI-87 Conference, July 1987 in Seattle, WA. Published papers have accompanied presentations at the AAAI workshop, the NASA workshop and the AAAI conference. Also received during FY87 was a NASA Tech Brief award associated with the STAR language. Imaging spectrometer instruments such as AVIRIS and HIRIS will increase the need for efficient powerful tools for analysis of data. Techniques developed in the SPECTRUM system should apply to data analysis for these and other future instruments. Of independent interest to the Artificial Intelligence community are the techniques developed in SPECTRUM for combining symbolic and numerical processing and supporting a mixed initiative control environment.

During FY88, the investigation will be shifted toward the use of Artificial Intelligence techniques in autonomous, on-board data analysis applications. Of particular interest are (1) the generation of high level data interpretation for providing feedback to the control mechanism for a spacecraft and (2) the efficient management of telemetry resources based on an initial, on-board interpretation of the data.

TECHNICAL CONTACT: Jerry Solomon, JPL (818) 354-2722

KNOWLEDGE-BASED EXPERT SYSTEM FOR HYPERSPECTRAL IMAGE ANALYSIS (SPECTRUM)

(506-45-11-01)



Concurrent Processing Research

The objective of this work is to perform fundamental research by developing algorithms that map efficiently to computers with both very large numbers of processors and high speed connections between the processors, for application to NASA problems. The approach taken has been to implement a wide variety of applications on the highly parallel SIMD architecture of the Massively Parallel Processor (MPP) in order to understand the robustness of this type of computer. During FY87, five very different algorithms were demonstrated to run in the MPP array unit: Pure LISP, general ray tracing, recursive function evaluation, solution of sparse linear systems, and cellular automata. The first three are inherently irregular in nature and had never been effectively mapped to the grid-like SIMD architecture. The recursive function evaluation and cellular automata are able to take exceptional advantage of the bit-serial nature of the MPP processors.

Pure LISP and general ray tracing were implemented based on "sort computation", a twist to generalize sorting which was developed under this RTOP. Sort computation allows computational operations such as aggregation and distribution of data values in keyed records to take place while the records are being sorted. The only time required is that for the sort plus that for the computation. Both sorting and computation can be performed very rapidly on the SIMD architecture (Figure 1) allowing sort computation to be used judiciously but whenever necessary as the mechanism for causing data records to rendezvous with each other. It also inherently performs load balancing among the processors. The unoptimized pure LISP interpreter evaluates the functions: CAR, CDR, CONS, EQ, ATOM, COND, APPLY, EVAL, LAMBDA, and EVLIST. The ray tracing approach is based on an algorithm that finds the intersection of light rays and objects in a 3-dimensional space. Both applications are written in the MPP Parallel FORTH language.

A computationally intensive recursive function used in the study of climatology was parallelized and executed on the MPP 4000 times faster than on a VAX-8650. A generalized hexagonal grid cellular automata for application to magnetohydrodynamic simulations was implemented and clocked at .85 billion site updates per second. A package which solves a sparse linear system of equations up to 3969 by 3969 representing a grid-graph was demonstrated using the Parallel Nested Dissection (PND) algorithm of Reif and Pan.

In FY88 we expect to optimize and enhance the parallel ray tracing algorithm and apply it to physical simulations such as foliage canopy modeling and to visualization of scientific data. We will also quantitatively compare the results of hydrodynamic simulation using the cellular automata technique with the results of more traditional PDE or finite element simulations. In addition we will develop a database concept which takes advantage of the characteristics of highly parallel architectures.

TECHNICAL CONTACT: Dr. John E. Dorband, GSFC (301) 286-9419

CONCURRENT PROCESSING RESEARCH

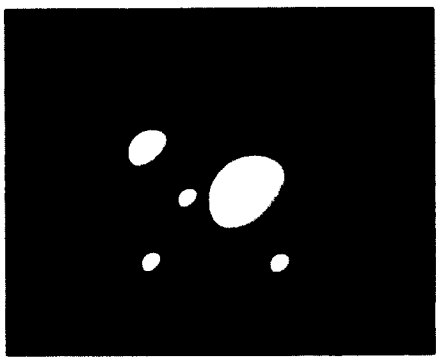
ACCOMPLISHMENTS

Demonstrated running in the MPP array unit:

- Pure LISP
- General Ray Tracing
- Recursive Function Evaluation
- Solution of Sparse Linear Systems
- Cellular Automata

BENEFITS

- Foliage Canopy Modeling
- Scientific Data Visualization
- Solid Modeling
- Thermal Modeling of Spacecraft
- Higher Speed Fluid Simulation
- Animated Graphic Generation for Robotics



GENERAL RAY TRACING

RECURSIVE FUNCTION EVALUATION

CELLULAR AUTOMATA

Computationally Efficient Tools for Parallel Processor Performance Prediction

The prediction of probable performance on parallel processors is an important problem, both to computer system architects and to application developers. During the design process, computer system architects need a means for evaluating the payoff of various system architecture alternatives. Similarly, application developers need a means for determining which of a number of models to choose for detailed development, given a particular available computational facility. Alternatively, given a model of an application to be developed, a means for choosing between a number of alternative parallel computer systems is needed.

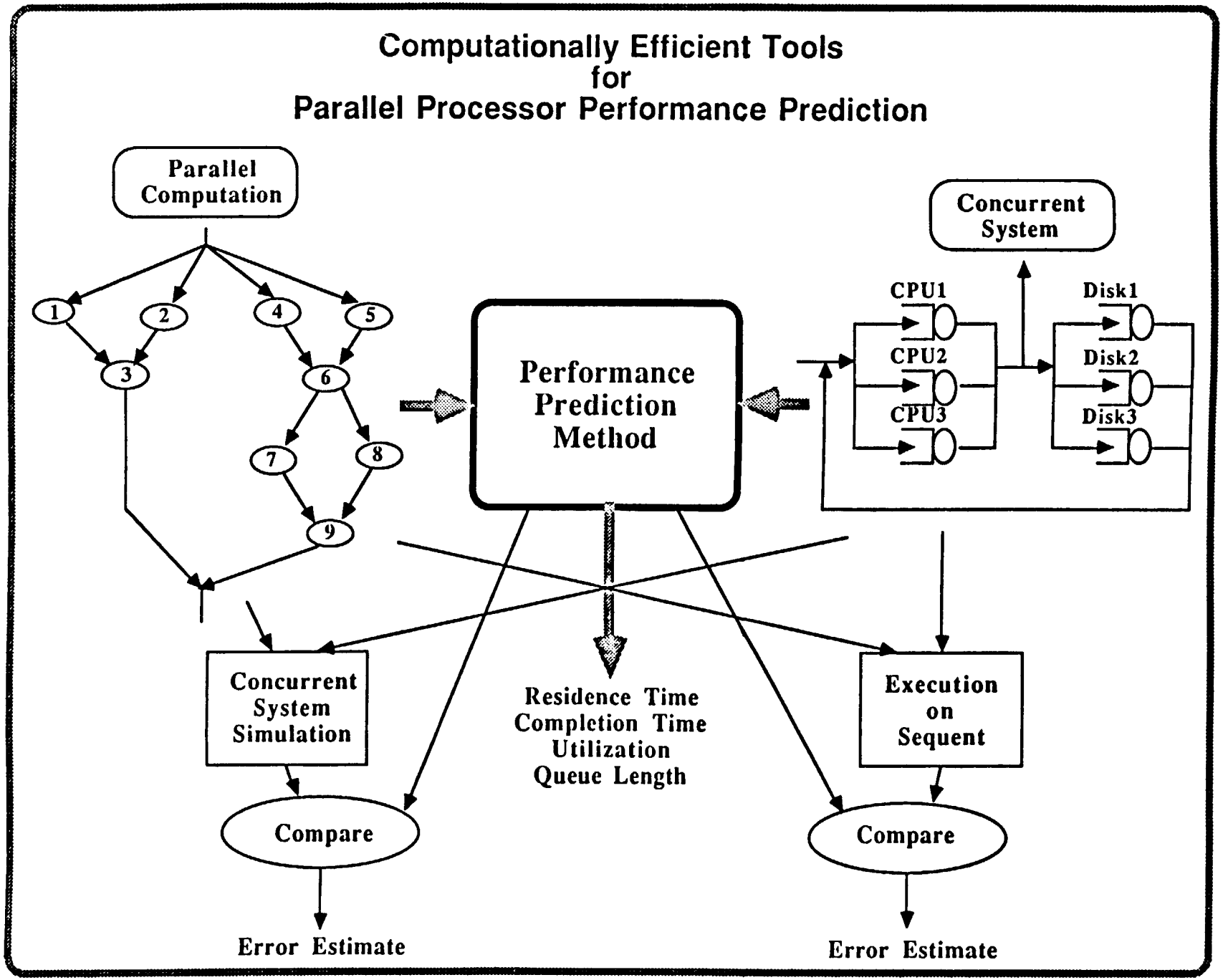
The **Performance Prediction Method**, which is the basis for the newly developed tool, takes the descriptions of a parallel computation and of the concurrent system as inputs. The parallel computation is modeled as a task system with precedence relationships expressed as a series-parallel directed acyclic graph. Resources in the concurrent system are modeled as a network of queues and servers. Using these two models, residence time of each task, completion time of the task system, as well as queue length and utilization of each resource in the concurrent system can be estimated by the proposed method.

The basis for the performance prediction method is an extension of queuing network models to take into account the effect of concurrency in the computation. Exact analytical analysis using finite state Markov chains is infeasible for large systems due to its exponential complexity in the number of states. The approximate method developed here has a very reasonable accuracy and was validated against both detailed simulation and measurement of a commercial multiprocessor. The algorithm is iterative and the time complexity of each iteration is $O(N^2K + N^3)$. The space complexity of the algorithm is $O(N^2K)$ where **N** is the number of tasks in the computation and **K** is the number of resources in the concurrent system. Convergence can usually be achieved in less than a dozen iterations.

These tools are expected to be useful in the evaluation of different concurrent architectures (especially in evaluation of proposed architectures), in the detection of bottlenecks in hardware and software, and in the comparison of different task allocation and partitioning schemes.

TECHNICAL CONTACT: Professor Michael Flynn, Stanford U. (415) 723-1450
Dr. Stephen F. Lundstrom, Stanford U. (415) 723-0140

Computationally Efficient Tools for Parallel Processor Performance Prediction



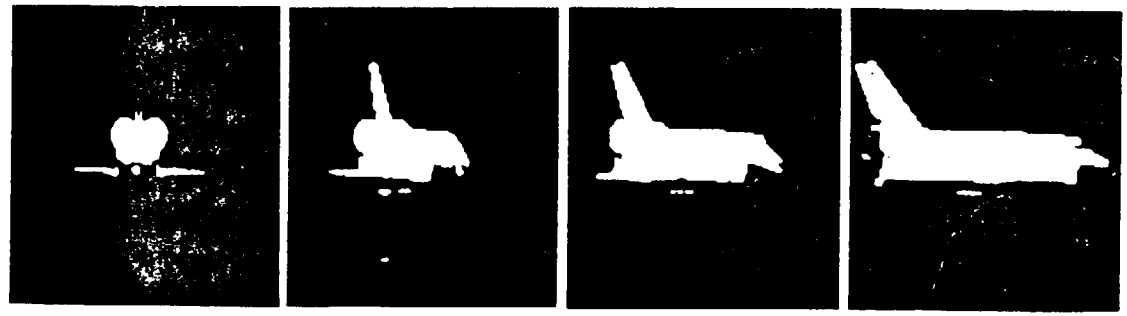
Optical Processing

A long-term application of the optical correlation research being conducted by the Optical Processing Group is in the area of machine vision for Space Station autonomous and semi-autonomous systems. Specifically, it is hoped that an optical correlation system would serve as an object list generator whose output would be a catalog of the objects present in viewed scene and their relative location. In operation, the correlator employs a spatial filter matched to a given object to scan for its presence. In the last year, significant progress has been made in terms of enabling the performance of these so-called matched spatial filters (MSF's) in a high-speed optical correlation system.

Accomplishments have occurred both in the theoretical and experimental realms. Theoretically, a new mathematical technique has been developed for MSF construction. Through the use of this technique, both the shape and intensity of the output peak produced by the MSF can be completely controlled and tailored to a specific application. The new MSF filters produce narrow output peaks (shown in the state-of-the-art 1987 figure) enabling the identification of multiple objects in a viewed scene. In addition, the MSF's produced are capable of recognizing an object regardless of its geometric distortion (scale, orientation and aspect angle). This is accomplished by designing the filter to produce equal intensity peaks for a set of reference images. On the experimental side, the MSF's have been input to the optical correlator at the video rate of 30 frames/second representing an improvement by almost an order of magnitude over values presented in the literature. This can be viewed as a significant step toward a real-time capability for the optical correlation system.

TECHNICAL CONTACT: Dr. David Jared, ARC (415) 694-6525

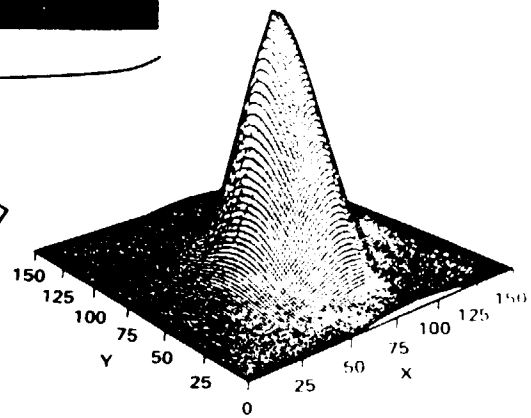
OPTICAL PATTERN RECOGNITION



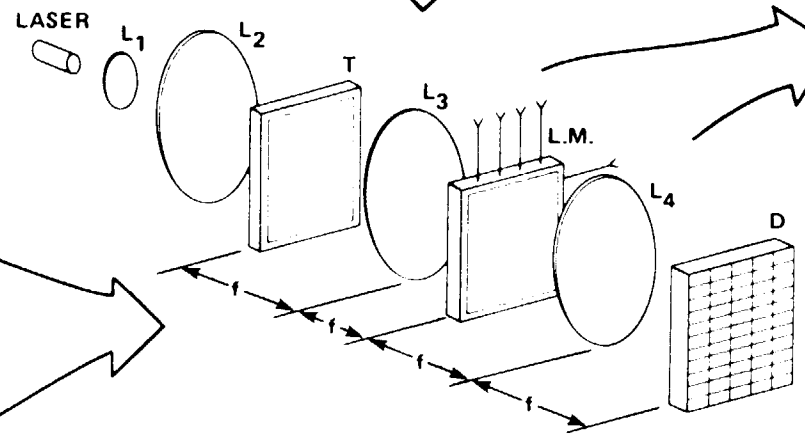
REFERENCE IMAGES

CORRELATION PLANE OUTPUT

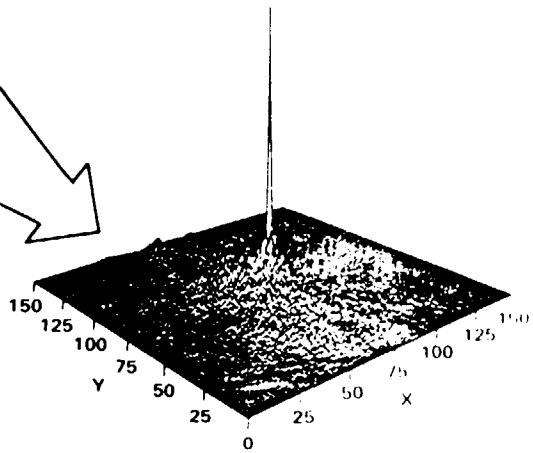
STATE-OF-THE ART 1986



INPUT IMAGE



STATE-OF-THE ART 1987



- Applications of Optical Pattern Recognition:
  - Visual scene understanding: Autonomous Vehicles, Automated construction, Telepresences.
  - Spectral analysis- Autonomous remote sensing, Astronomical observations.
- Advantages for Space Applications:
  - High-speed parallel processing, low power consumption, compact size, low weight.

- Progress Toward Implementation:
  - Comprehensive theory of distortion-invariant pattern recognition has been developed.
  - Development of Methodology for interfacing optical pattern recognition to Artificial Intelligence.

NASA AMES RESEARCH CENTER

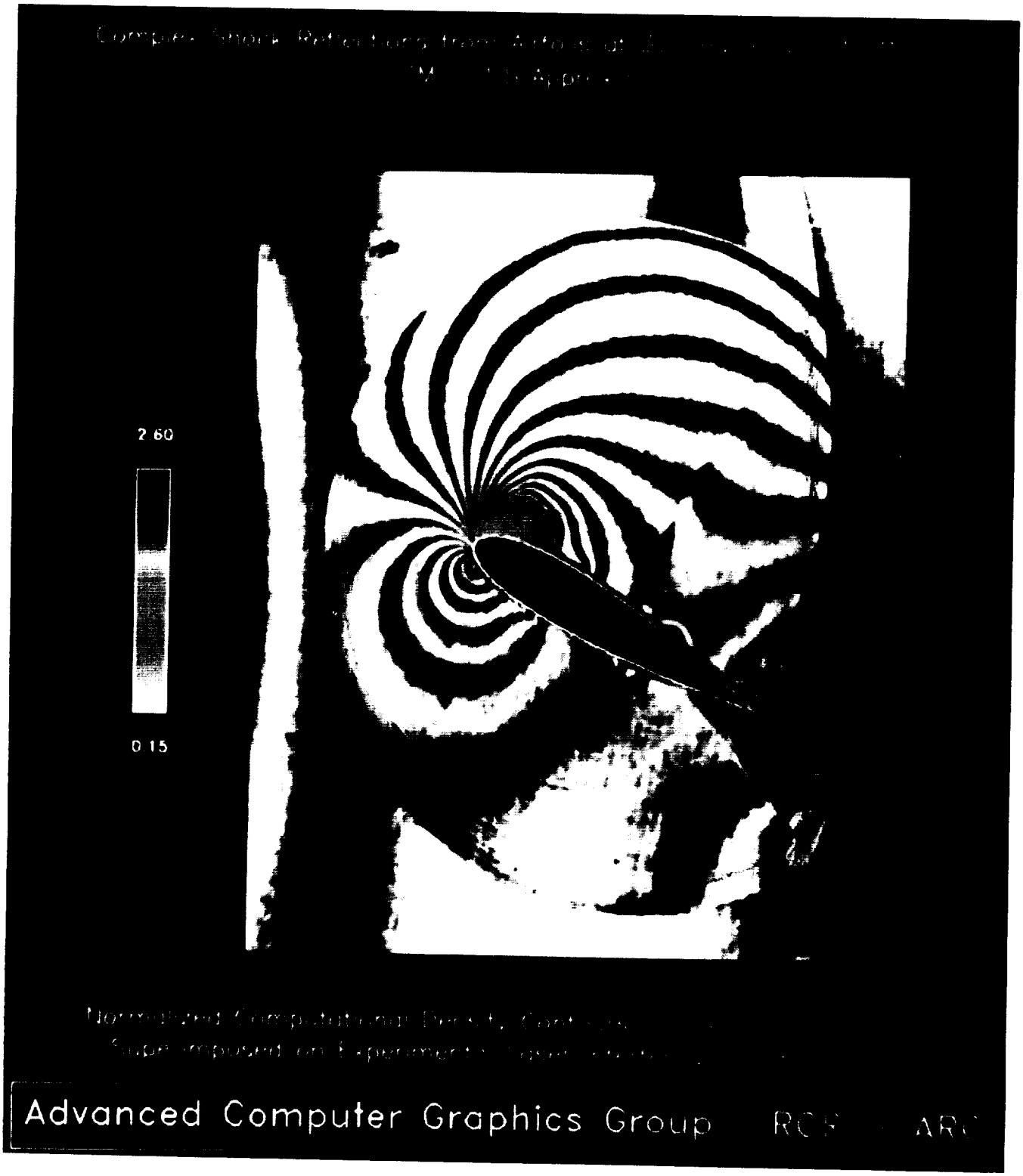
OAST-SPONSORED RESEARCH

Graphical Comparison of Experimental and Computational Results

This program at ARC is concerned with the development of innovative methods for the visualization of experimental and computational fluid dynamics results. The approach shown in the photo was to first digitize and store in raster image form an experimental holographic interferogram. Next the vector fields representing the computational density contours from a computational fluid dynamics program were transformed, scaled, color coded, and raster converted for overlay on the experimental image. The attached photo shows a comparison of experimental and computational simulations of shock wave impingement on a NACA 0018 airfoil. Effective comparison of complex numerical simulations of flow fields and the experimental measurements is one of the major challenges in aerodynamics. Methodologies to effectively compare these results, by utilizing advanced computerized visualization techniques, will provide a better understanding of the physics being investigated. Continued research and development in this area could lead to real-time coupling of experimental and computational fluid dynamics.

TECHNICAL CONTACT: K.G. Stevens, Jr., ARC (415) 694-5949

COMPARISON OF EXPERIMENTAL AND COMPUTATIONAL SIMULATION



A New Concept in Distributed Operating Systems (DOS)

Based upon advance information management concepts of objects and actions the objective was to develop and evaluate software operating systems for distributed computing.

The "object" is a means for implementing a new class of operating systems having features that are more capable than files or Ada Packages for managing data in both operation and recovery (Figure 1). "Objects" support temporary and permanent data, concurrency, distributed data, automatic or user-built access control, synchronization, recovery, global naming for rapid location and migration, and templates for creating new versions. Users interact via "processes" and "transactions" (Figure 2). "Transactions" supervise "processes" to assure consistent information states in the event communication delays or failures corrupt the data. "Processes" allow concurrent tasking with low-overhead for starting, suspending, restarting, and terminating.

A distributed operating system, CLOUDS (not an acronym) is in operation and test on a 4 VAX 750 - Ethernet system at Georgia Tech. The kernel, replicated at each site, is written in C and is suitable for general purpose computers connected by popular networking hardware. To simplify programmer interfacing, the languages C and Aeolus support CLOUDS object feature and UNIX programs are able to use CLOUDS objects. This makes the transition to CLOUDS evolutionary.

CLOUDS provides promising technology for a new class of distributed systems by providing a uniform environment, i.e., no machine boundaries, uniform procedural interfaces, no messages, no files, no complex I/O, no multiple copies to keep consistent for failure recovery, etc. It provides a research opportunity for NASA and the computer industry to answer many pertinent DOS operations, interface and performance questions.

Studies are underway to document performance and augment CLOUDS with standard features. A version will become resident at Langley for further study.

TECHNICAL CONTACTS: Dr. Richard LeBlanc/Dr. Partha Dasgupta, Georgia Inst. of Tech. (404) 894-2592

CLOUDS OBJECTIVE STRUCTURE - SIMPLE ACTION/OBJECT ACTIVITY

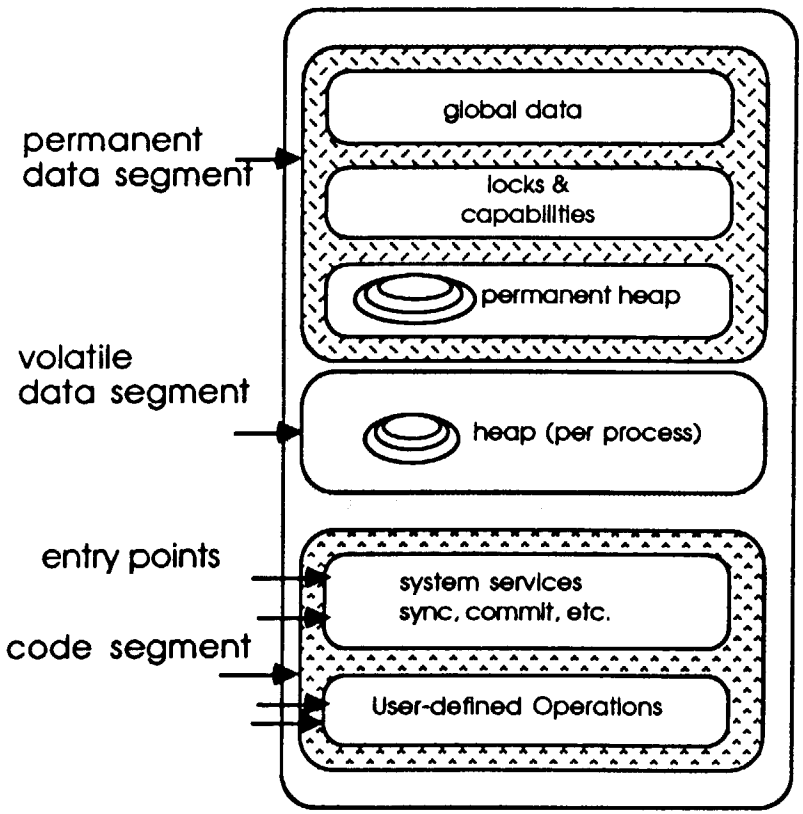


Figure 1 CLOUDS Object Structure

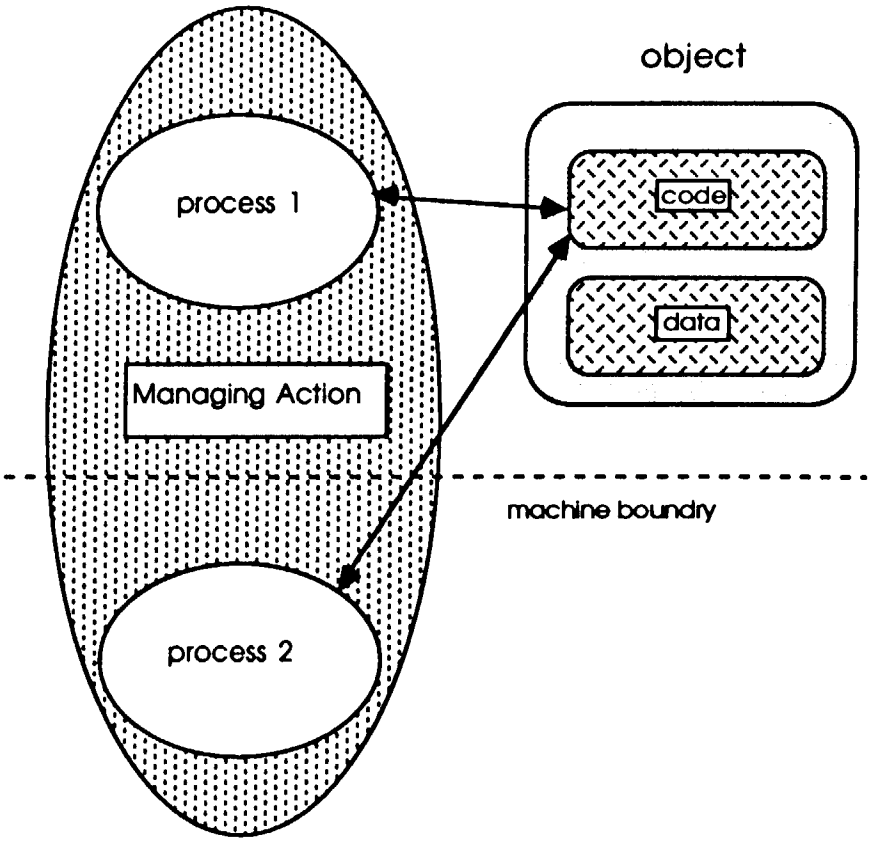


Figure 2 Simple Action/Object Activity

Software Management Environment

The objective of this effort is to perform research in key areas of software management leading to the development of an operational software system called the software management environment. This will consist of an integrated set of tools and software measures which will support the improved management and acquisition of large, complex software systems. Typical tools include rapid prototyping aids, quality assessment aids, as well as costs and scheduling predictors.

During this year, major efforts were put forth in defining the architecture of the integrated set of tools and concepts making up the SME. A report "Concepts and Architecture of the SME" was completed in 1987. Additionally, the implementation of the integrated environment was initiated with the first demonstration of this version scheduled for 12/87. Finally, the design of the system was expanded to contain a set of software models representing known characteristics of the software development process such as the typical life cycle resource expenditure. These models have been derived from empirical studies and will be stored as smoothed, refined representations of development characteristics and will be used by SME in assessing active project status.

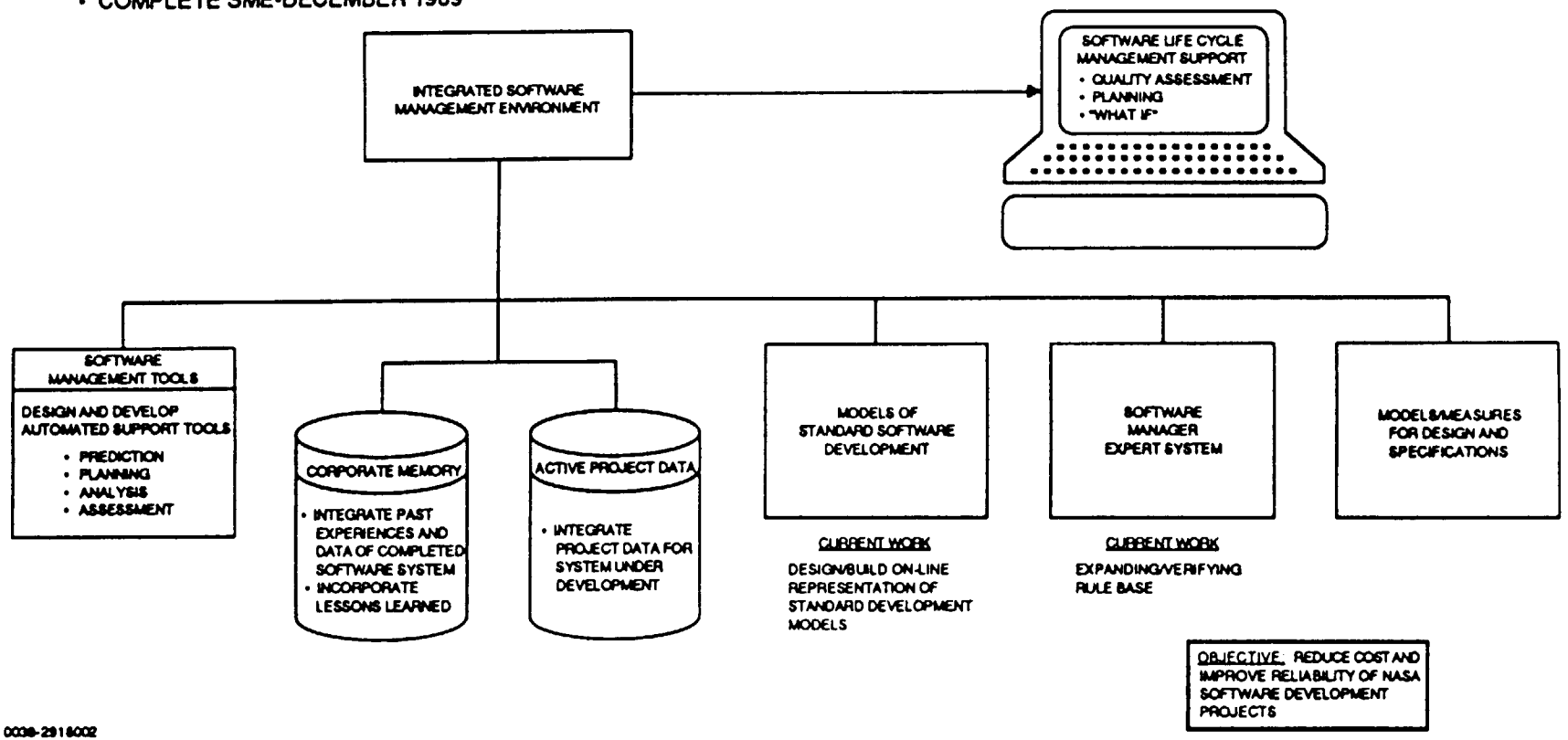
An attempt is now being made to incorporate all results of studies as well as AI tools into a single demonstration management environment.

TECHNICAL CONTACT: Frank McGarry, GSFC (301) 286-6846

SOFTWARE MANAGEMENT ENVIRONMENT

INTEGRATION OF:

- ANALYSIS TOOLS FOR MODELING AND MEASURING THE SOFTWARE DEVELOPMENT PROCESS
- EXPERT SYSTEM FUNCTIONS FOR COMPARISON OF CURRENT PROJECTS TO PAST EXPERIENCE TO PREDICT PROBLEM AREAS
- DEMO OF INTEGRATED VERSION-DECEMBER 1987
- COMPLETE PILOT APPLICATION AND EVALUATION OF SME-DECEMBER 1988
- COMPLETE SME-DECEMBER 1989



0038-2918002

A UNIX-Based Software Engineering Testbed

The objective of this research is to establish a host environment of networked computers to support software engineering research.

In order to accomplish this, first UNIX was selected as the basic environment. The UNIX system is a multi user, multi-process environment which includes utilities such as editors, compilers, and text formatters. Useful UNIX utilities were identified and exercised prior to their inclusion in the software engineering testbed. Network gateways and protocols for electronic mail and file transfer were established. The environment includes both local and internal networks with TRFS (Transparent Remote File System) and gateway connections to other external networks e.g., (LaRCNET, ARPANET, BITNET, CSNET, TELENT) via Ethernet. These networks support information exchange and resource sharing with remote sites. An Integrated Solutions, Inc., (ISI) UNIX-based system is being used as a testbed for prototype software engineering tools being developed under university grants.

A UNIX based environment has been established on an Integrated Solutions, Inc., microcomputer. The system consists of a file server and a graphics workstation. The workstation has a windowing facility which allows a single user to perform and monitor several concurrent activities. The workstation also has a graphics capability which can be used to create complex diagrams. SAGA components, developed under a grant at the University of Illinois, have been ported to the ISI for testing and evaluation. Electronic mail, file transfer and networked resources have been used to support collaborative work with researchers at other sites.

A UNIX-based capability to host products from leading universities is essential to fulfilling the objective of improving the quality of NASA software.

It is planned in the future to enhance the UNIX environment and evaluate the X-window facility for machine-independent user interface on the ISI diskless node. Then this testbed can be used for installation and evaluation of prototype software engineering tools from university grants.

TECHNICAL CONTACT: Kathryn A. Smith, LaRC/Sharon Beskemis, PRC-Kentron (804) 865-3535

SOFTWARE ENGINEERING TESTBED

Software Automation, Generation And Administration (SAGA)

The objective of this research is to investigate the methods and techniques for integrating and managing software development tools and processes so as to obtain improved software quality.

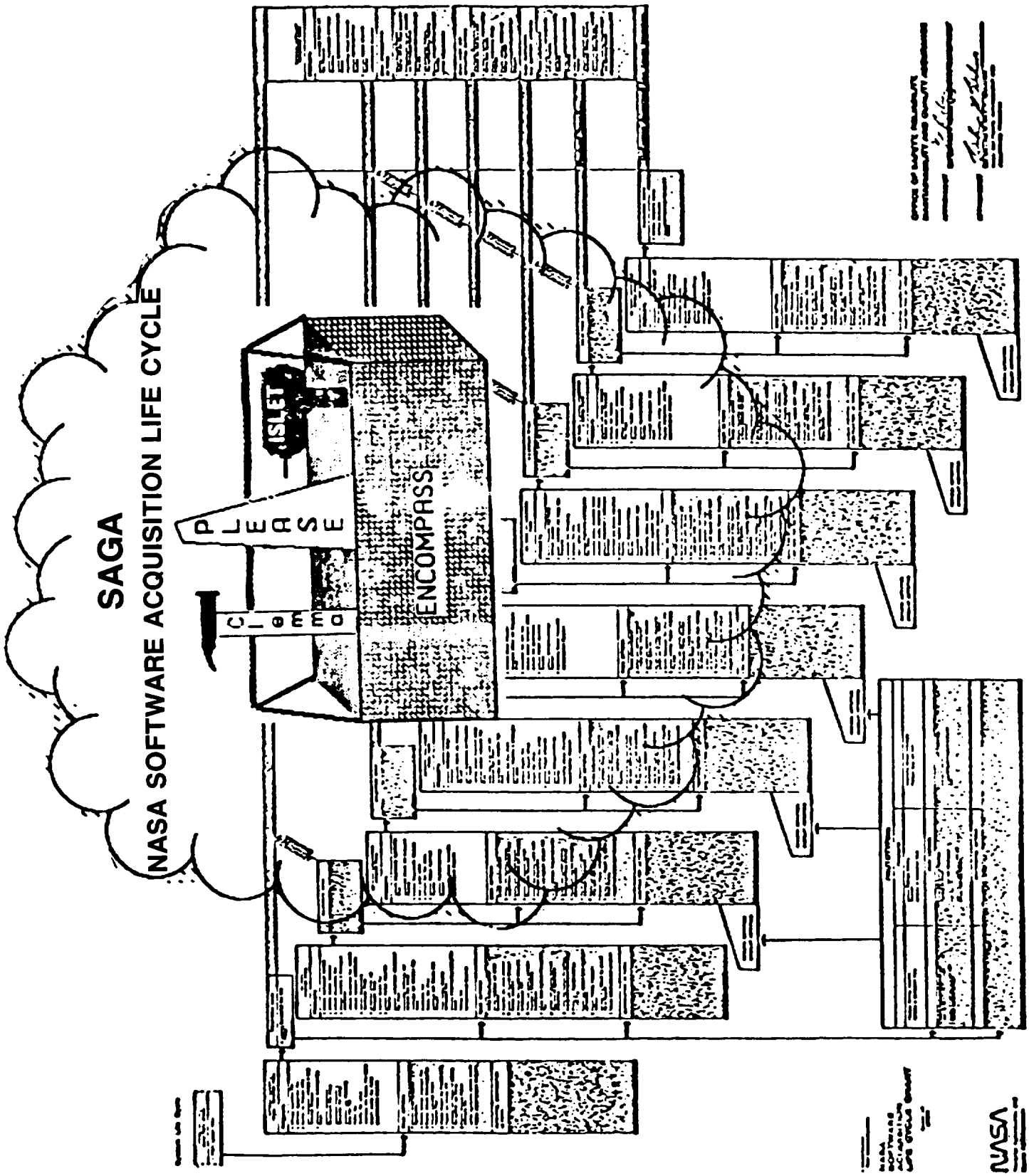
In order to achieve this, various software engineering concepts were studied and experimental special purpose tools examined. The NASA Software Acquisition Lifecycle requirements determined the software tools and techniques selection. These tools and techniques were used to develop ENCOMPASS, a prototype software development environment. Based on the idea of development by incremental refinement, ENCOMPASS includes an executable specification language (PLEASE), testing, and formal verification techniques. A number of software engineering concepts were studied and several special purpose tools have been developed as part of ENCOMPASS: PLEASE (Predicate Logic based ExecutAble SpEcifications), a wide-spectrum, executable specification and design language, supports construction of software in Ada; executable prototypes can be automatically constructed from specifications. IDEAL (Incremental Development Environment for Annotated Languages), an environment for programming in the small, is concerned with the specification, validation implementation, and verification of single modules. IDEAL is composed of a language-oriented editor, a proof management system, a prototyping tool, and a test harness.

An experimental, prototype software development environment ENCOMPASS (Environment for the Composition of Programs and Specifications) is installed and operating. It was developed as part of the SAGA project at the University of Illinois. ENCOMPASS provides automated support for several aspects of the NASA software acquisition lifecycle including, requirements, design and implementation. Executable specifications are supported via the specification language PLEASE.

SAGA research results influenced the form and content of the NASA Software Acquisition Lifecycle and Documentation Standards, which now govern all NASA software projects.

In the future we hope to install ENCOMPASS and evaluate prototype software tools on the LaRC UNIX software engineering testbed and begin quantification of improvement in software quality resulting from its rise.

TECHNICAL CONTACT: Dr. Roy H. Campbell, U. of Ill. (217) 333-0215
Kathryn A. Smith, LaRC (804) 865-3535



Software Life Cycle Simulation (SLICS) Model

The objectives of this task are: 1) To develop and prove the technology to provide software managers with quality life cycle simulation models on par with other technical simulation tools; 2) to apply the developed technology, SLICS, for developing a software life cycle model for a Space Station application, the Software Support Environment (SSE); and 3) to initiate research for integrating the SLICS technique with Expert Systems technology.

The technical approach involves: utilizing the knowledge obtained from modeling a Space Shuttle application, the Space Transportation Automated Reconfiguration (STAR) project, to develop the SLICS-SSE model; developing a survey instrument to gather SSE project characteristics, management heuristics, and input data; and finally, including university based expertise in the study of integrating the SLICS technique with Expert Systems technology.

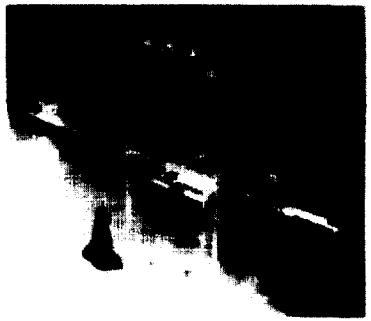
During FY87 the SLICS technique was applied to model a Space Station application, the SSE. Initially, a survey instrument was constructed and used to acquire SSE project data and management heuristics. Then, based upon an analysis of the collected data, the SSE model was developed and the output from the first version of this model was reviewed and approved by SSE project managers at JSC. Next, a user friendly interface was developed and integrated with the model, and a user's guide for its use completed. In addition, a SLICS technology video was produced and later reviewed by OAST. Finally, rough drafts for two papers, "Hybrid Expert Simulation System (HESS)" and "Computer-Aided Software Development Process Design", which describe the concept of integrating the SLICS technique with Expert System technology, were completed.

A dynamic simulation model of the software life cycle process portrays software development activities and their interrelationships. This modeling technique provides a laboratory where changes in software standards, methodologies and management policies can be tested prior to adoption. In essence, the model is a tool whereby the uncertainties associated with budgetary and schedule planning can be reduced, strategic support for technology development and productivity improvement can be provided, and medium to large software projects, such as SSE, can be better managed.

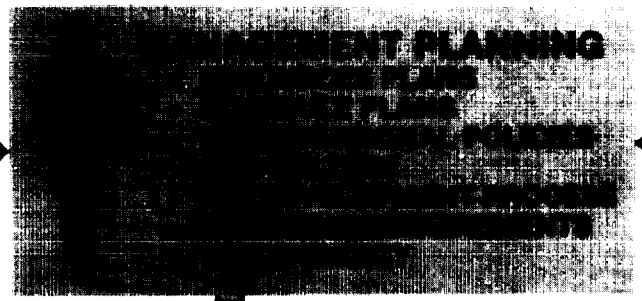
During FY88 a generic software life cycle model that will accommodate various NASA managed software projects will be designed, software metrics for use in collecting project data and calibrating and validating the model will be researched and developed, and a design for integrating the SLICS technique with Expert Systems technology will be initiated.

TECHNICAL CONTACT: Chi Lin, JPL (818) 354-4069

SLICS: SOFTWARE LIFE CYCLE SIMULATION MODEL

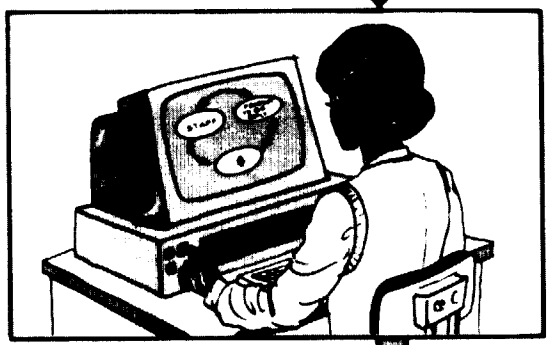


SPACE STATION APPLICATION



REVISE PLANS/ STRATEGIES

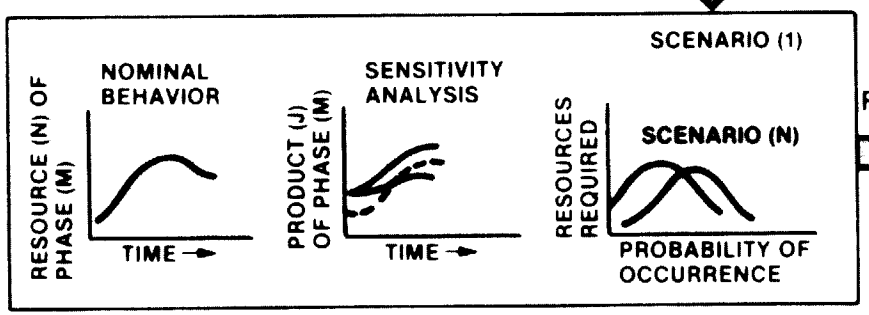
INPUTS



SLICS SIMULATOR

CONSTRAINTS

- BUDGET
- SCHEDULE
- FUNCTIONALITY
- MAX. STAFF AT A GIVEN TIME
- TOTAL MAX. STAFF



SLICS GENERATED OUTPUTS

RECOMMENDATIONS

Controls and Guidance - Aeronautics

The overall objective of the Aeronautics Controls and Guidance Program is to provide a validated technology base leading to the development and exploitation of new concepts, analysis and design methodologies, and flight systems for future civil and military aircraft. This will provide increased efficiency, effectiveness, reliability, and safety. The program is organized into generic elements and vehicle-specific elements. The generic elements are Control Theory, Guidance and Display Concepts, and Flight Crucial Systems. Vehicle-specific elements are Generic Hypersonics, Subsonic Transport/Commuter/General Aviation, Rotorcraft, and Fighter/Attack.

Research in the Control Theory element is directed toward the improved flight control analysis and design methodologies for highly integrated, robust flight control designs. These will account for strongly coupled, nonlinear plant dynamics. To develop an understanding of the dynamics of new vehicles, such as VSTOL and High Alpha research vehicles, system and parameter identification methods are being developed. Emerging technologies, such as artificial intelligence, are used in developing new approaches and concepts. Guidance and Display Concepts research involves the development of automation concepts and advanced display media. Flight Crucial Systems research is directed toward the development of design, assessment, and validation methodologies for flight crucial systems. Increasing emphasis will be placed on developing validation methods for real-time, knowledge-based systems in flight crucial applications.

Generic Hypersonics research concentrates on the integration of flight control, propulsion control, sensors and displays. Subsonic Transport research seeks technologies which will provide safer, more efficient civil transport operations in the future National Airspace System. The major thrusts are airborne sensing, detection and avoidance of wind shear and the development of efficient 4-D guidance and control systems leading to enhanced efficiency, safety and capacity in the terminal area. Technology developments in automated mission management and goal-directed flight path management leading to automated nap-of-the-earth flight capability are areas of emphasis in the Rotorcraft element. The focus in the Fighter/Attack element is on advanced guidance and control concepts for future super-agile aircraft, development of flight validation techniques for imbedded expert systems, and the development of multidisciplinary design methodology for highly interactive dynamic systems.

The Aeronautical Controls and Guidance Program involves analytical and experimental research performed by in-house, university and industry personnel. Extensive use of ground-based simulation is a characteristic of the program with selected flight experiments in a variety of aircraft. In the future, more emphasis will be placed on carrying the most promising concepts into flight evaluation and validation programs.

PROGRAM MANAGER: John D. DiBattista
NASA/OAST/RC
Washington, DC 20546
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Take off Performance Monitoring System

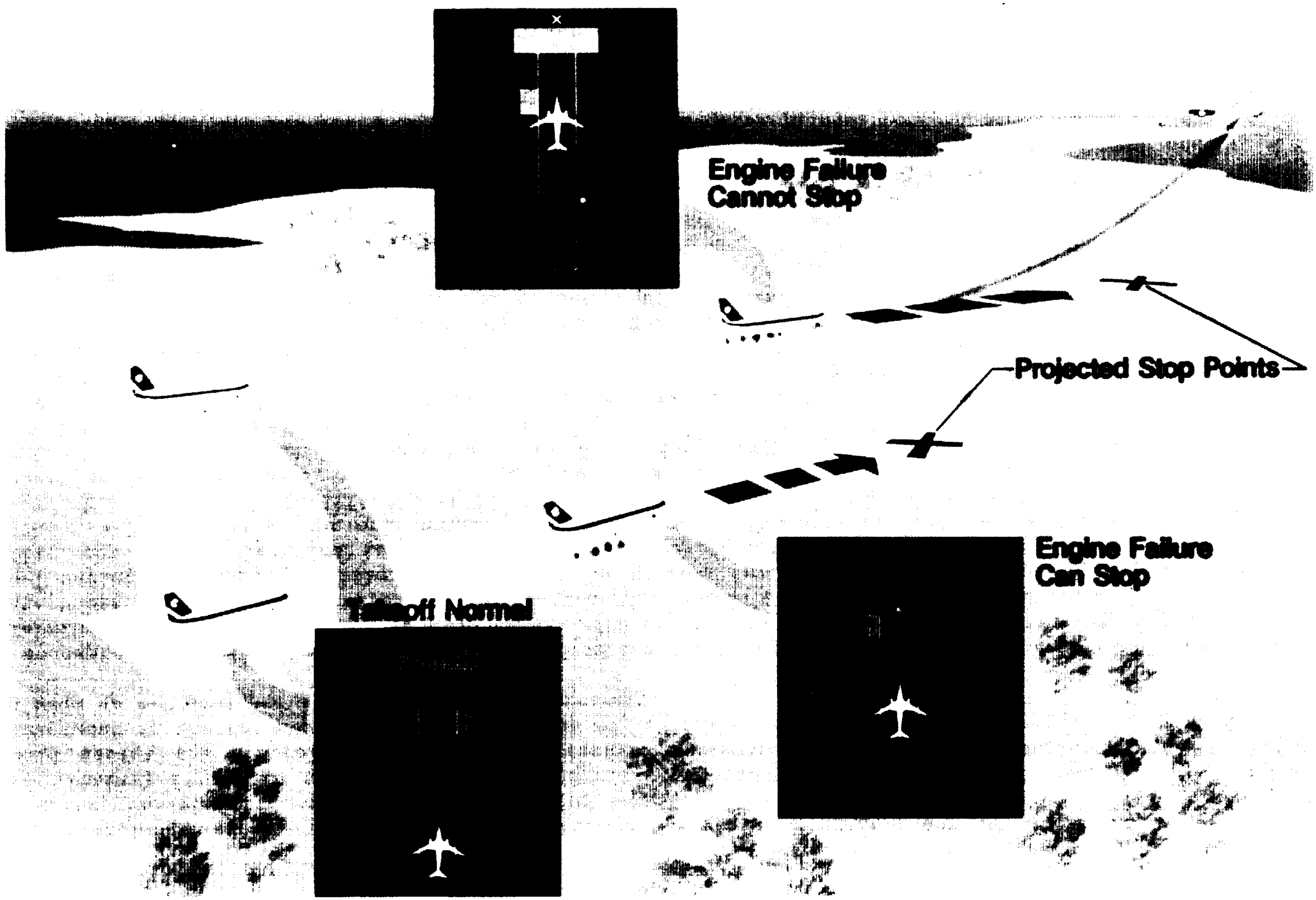
The objective of this project is to provide the flight crew the graphic and numeric information to aid in decision-making, especially as it applies to continuing or aborting a takeoff. Currently, flight management systems do not provide any aids for the takeoff flight phase even though statistics indicate that accidents during this phase account for about 12% of all aircraft related accidents. It is also known that most takeoff-related accidents are attributable to some form of performance degradation.

In order to help alleviate this problem, a display system has been developed and evaluated in a full task simulation by more than 30 experienced multiengine pilots representing NASA, FAA, USAF, commercial airlines, and the industry. Information provided to the crew via the display includes: a) current position and airspeed; b) predicted location for reaching decision speed (V_1); c) groundroll limit for reaching rotation speed (V_R); d) predicted stopping point for an aborted takeoff; e) engine failure flags; and f) an overall situation advisory flag. In general, pilots liked the display and felt it would contribute significantly to improved flight safety. A captain's display (HUD) is currently being evaluated.

This concept will now be evaluated in flight during FY88. These activities will be extended and merged with the high-speed rollout and turnoff efforts in order to provide a takeoff and landing performance monitoring display.

TECHNICAL CONTACT; Dave Middleton, LaRC (804)865-3595

TAKEOFF PERFORMANCE MONITOR



Evolutionary Time-Based Terminal Flow Control Concept

The objective is to define, develop, and evaluate an evolutionary ATC concept which would improve the capacity, reliability, and economy of extended terminal flow operations (en route approach, transition, and terminal flight to the runway) when used with projected ground and avionic hardware. The concept would assist the controller in performing traffic management, sequencing, scheduling, and ATC flight management in the extended terminal area. The evolutionary system needs to accommodate today's aircraft, as well as 4-D equipped advanced-technology aircraft.

A concept for extended terminal, time-based flow control has been developed and incorporated in the TAATM (Terminal Area Air Traffic Model) simulation. The concept is a ground-centered, time-based process which integrates en route flow control, runway sequencing, scheduling, and ATC flight management together with fuel saving flight-idle profile descents in order to both fully utilize runway capacity and improve fleet efficiency. The algorithm issues ground derived speed and profile descent instructions to aircraft without 4-D capability, but only metering fix and runway time objectives to 4-D equipped aircraft. The algorithm, employing simplified models, is designed for integration into the manual, voice-linked ATC system in an evolutionary manner and to also accommodate NAS upgrade features such as data link and further ground automation. Interarrival time separations can be flexible as well as fixed.

A fast-time parametric sensitivity evaluation of the basic extended terminal area flow control concept with non 4-D traffic was done using TAATM in a four corner-post, Denver runway 26L configuration with IFR arrival commercial traffic. Results identify and show the effects of such key variables as delivery time errors, aircraft separation requirements, delay discounting, wind, and flight technical errors. For example, the accompanying future indicates that a metering-fix delivery error deviation of less than 30 seconds is needed to maintain full capacity.

Identification of key parameters for terminal, time-based ATC operations, along with novel approaches to improve system performance, is critical to designers of the future automated ATC system.

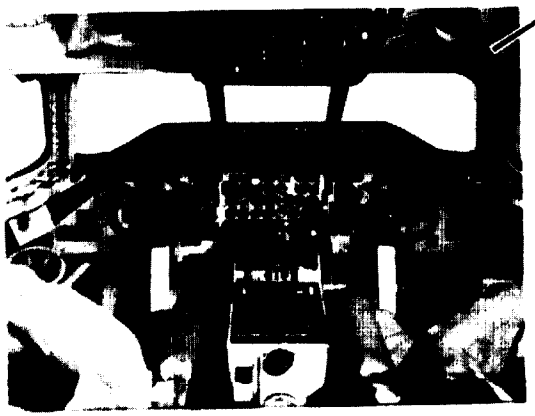
A follow-on effort will define requirements for handling a mix of 4-D and non 4-D arrival traffic. If the concept still appears feasible, then real-time tests using pilots, cockpit simulators, and controllers will be conducted to test its robustness to human interactions.

TECHNICAL CONTACT: Leonard Credeur, LaRC (804) 865-3917

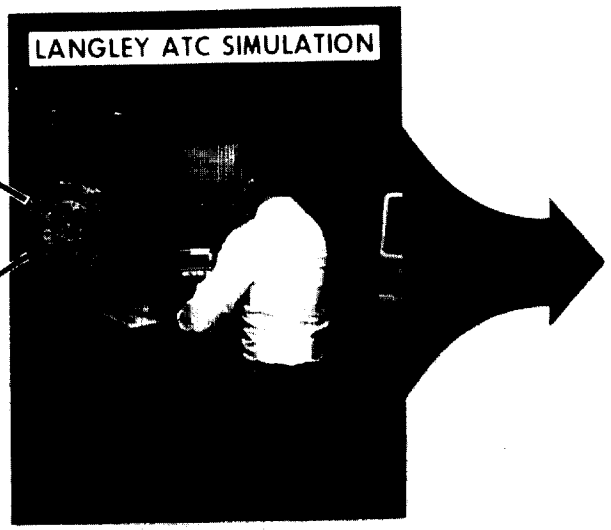
TIME-BASED TRAFFIC MANAGEMENT

CONVENTIONALLY-EQUIPPED FLIGHT DECKS

ATOPS B-737 FORWARD FLIGHT DECK

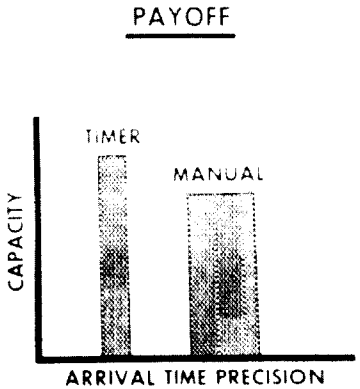


DC-9 SIMULATOR CAB



"TIMER"--CONTROLLER AIDING

- COMPUTER GENERATED ADVISORIES
- CONTROLLER/SYSTEM INTERFACES



Crew Station Research and Development Facility

The system complexity and high workload of the next generation of Army helicopters is a major technology concern for NASA and the U.S. Army. In response to these concerns, the Crew Station Research and Development Program was established by the Army to study the issues of battle captain performance for one man versus two man crews. This program included a full-mission piloted R & D simulator (CSRDF), which was developed under NASA management and is located at NASA-Ames Research Center.

This facility also consists of a distributed computer system with several manned stations which play different roles in the experiments. These are a tandem glass cockpit, three Blue/Red team stations to simulate other scenario aircraft; a White station to simulate the communications with ten other scenario participants; and the Experiment/Operator Console (EOC), where a team of Army experimenters and NASA personnel will control and monitor the mission scenario that is used to test the crew members.

The focal element of the facility is a two seat tandem helicopter cockpit which has been designed to represent the technology which is expected to be available in the Army LHX. The primary simulator flight display for the pilot is a wide-field-of-view Fiber Optic Helmet Mounted Display (FOHMD) which presents a panoramic view of the world coupled with sensor outputs and symbology for pilotage, threat alerts and weapon release.

After completing Government Acceptance Tests at the Contractor's Plant in April 1987, the CSRDF was used on-site for an initial evaluation by a team of Army researchers. The system became operational at the Ames Research Center in September 1987 and is being extensively used, prior to beginning extensive use in support of the LHX program.

TECHNICAL CONTACT: D. Jones, ARC (415) 694-6171

Automated NOE Flight Mission Planning

The objectives of mission planning for the Automated NOE program is to define,develop, and demonstrate an effective route planner/replanner for low-altitude/NOE helicopter flight. The planner would support fully autonomous flight of a single pilot scout/attack helicopter by reducing peak workloads, providing better management of fuel and other resources, minimizing threat exposure and making real-time changes in the mission plan to meet changing objectives.

An SBIR Phase II contract with TAU Corp. provides for a mission planner by 1988 using a dynamic programming algorithm to produce a globally optimum plan. An early version of this software is operational on a SUN3/160C workstation in the Aircraft Automation Laboratory providing the path to be displayed on a NASA developed color graphics display.

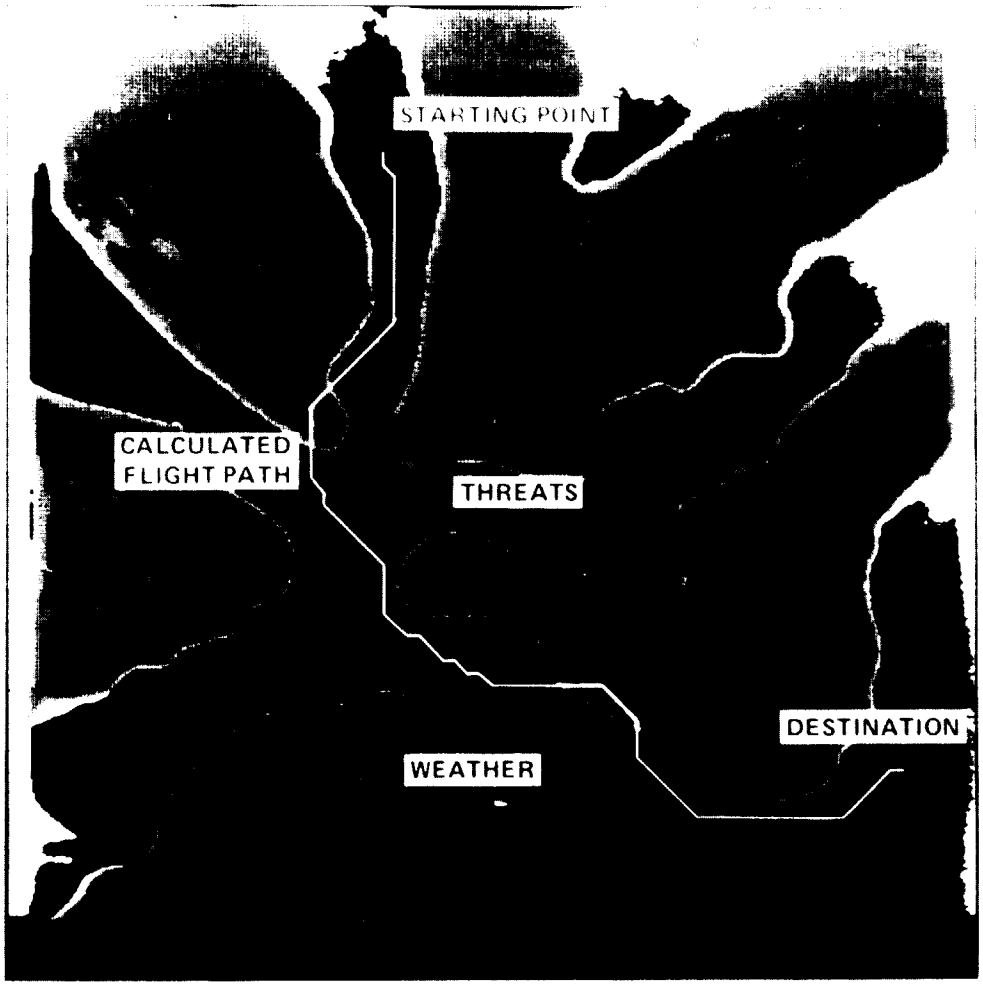
A second contract with the Charles Stark Draper Laboratory has initiated the development of a planner using a heuristically guided simulated annealing algorithm for goal selection and sequencing. Between goal objectives, this planner uses an A search to provide accurate forecasts of fuel, time and lethality of the path. As the algorithm searches for the best plan, the "best plan so far" is always available.

A third contract (SBIR Phase I) awarded to Odetics, Inc. seeks to develop a Threat Expert System Advisor in Phase II which would include an expert system Route/Mission planner. The ultimate goal would be flight test of this AI approach on a suitable helicopter.

TECHNICAL CONTACT: Leonard McGee, ARC (415) 694-5443

AUTOMATED NOE HELICOPTER FLIGHT

PATH PLANNING



GROUND HEIGHT SCALE

LOW HIGH

Reconstruction of Low-Level Microbursts

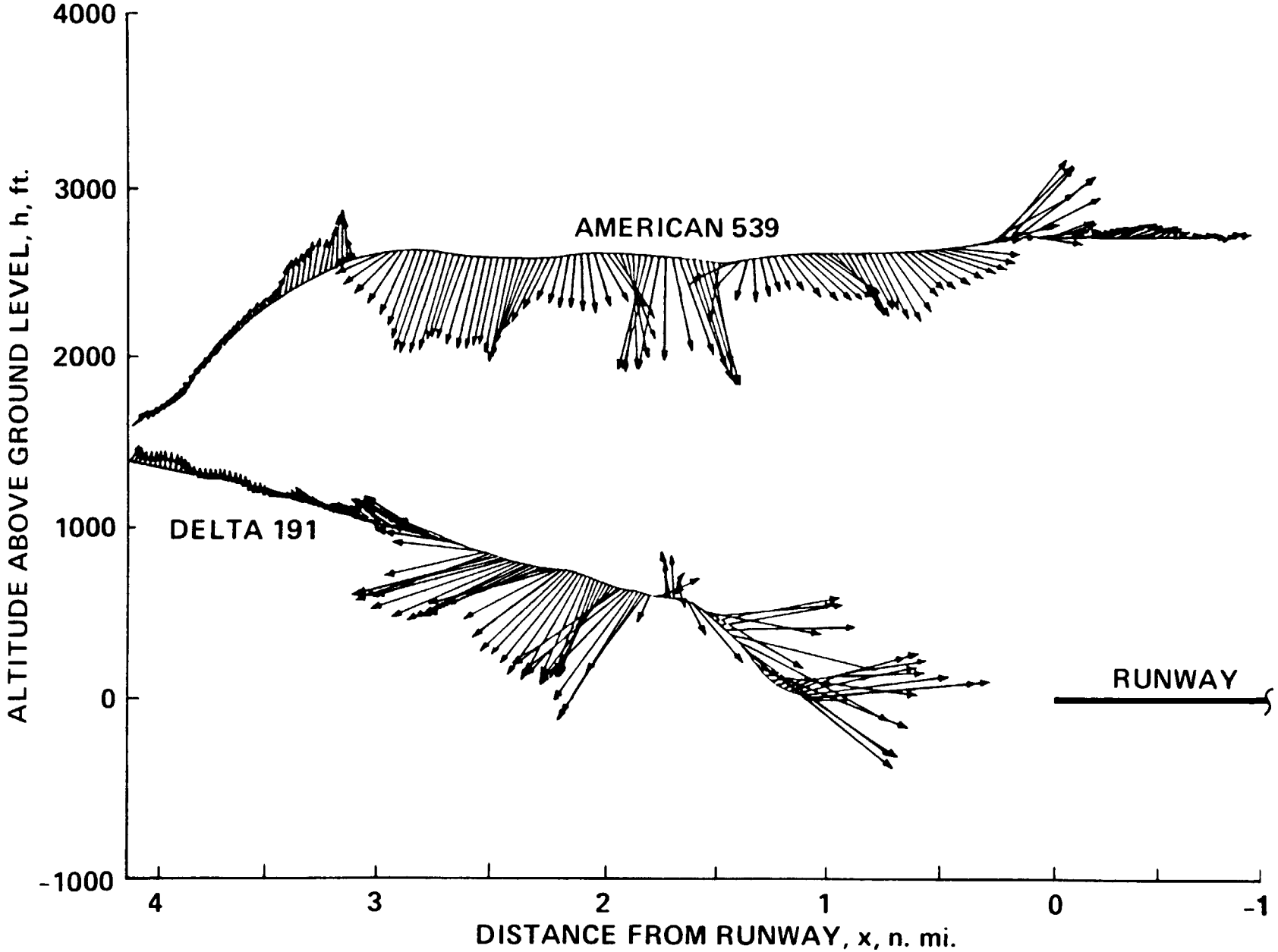
Low-level microbursts are a continuing problem that must be better understood in the interest of aircraft safety. One way to investigate the nature and cause of severe microburst encounters is through analysis of airline flight records. In the past such analysis was hindered by insufficient data, but more recent microburst encounters have involved modern airliners with digital flight data recorders. Advanced analytical methods have been developed at Ames to utilize these digital records, along with ATC radar position records, in order to reconstruct the time history of the wind vector during severe microburst encounters.

In cooperation with the National Transportation Safety Board, these advanced analytical methods have been applied to the digital flight records from two aircraft, Delta 191 and American 539, that penetrated the microburst at the Dallas/Ft. Worth airport on August 2, 1985. Delta 191 encountered the microburst on final approach and contacted the ground about 1 mile short of the runway. The results for Delta 191 show that the aircraft encountered a strong downburst followed by a strong outflow accompanied by large and rapid changes in the vertical wind. The rapid changes in the vertical wind detected near the ground are attributed to vortex-induced turbulence, American 539 made a go-around 110 sec after Delta 191 and traversed the microburst at an altitude about 2,500 feet above the ground. The measured winds during this go-around indicate a broad pattern of downflow in the microburst with regions of upflow at the extreme edges. These combined results indicate a microburst that is increasing in size with vortex induced turbulence embedded in a strong outflow near the ground.

These measured winds obtained from digital flight records onboard modern airliners provide a new detailed description of the turbulent wind environment in a severe microburst. These measured winds are being used in manned flight simulators and in aircraft control studies to better understand the operating problems in low-level microbursts and are being used as a standard of comparison in the ongoing experiments and modeling of microbursts involving vortex rings.

TECHNICAL CONTACT: R. Bach/R. Wingrove, ARC, (415) 694-5429

WIND VECTORS IN THE DALLAS-FORT WORTH MICROBURST RECONSTRUCTED FROM TWO AIRCRAFT



Demonstration of Automation Tools for Control of Air Traffic

In recent years NASA Ames has worked with the FAA to develop automated techniques for assisting controllers in managing terminal area traffic, in order to reduce delays, fuel consumption and controller workload. These techniques are based on accurate prediction and control of aircraft flight paths in space and time, referred to as 4D guidance. Recently, ground-based algorithms have been developed that can provide such capability to aircraft not equipped with on board 4D guidance systems. This development together with new interactive computer graphics workstations allows early implementation of advanced automation concepts. In an effort to demonstrate this potential to FAA users, NASA plans to implement and demonstrate controller automation tools at an Enroute Air Traffic Control Center. Planned for late 1988, the demonstration will be especially timely permitting the FAA to evaluate these concepts for potential application in the new Controller Suites of the Advanced Automation System, scheduled to become operational in the early 1990's.

Two types of controller tools will initially be incorporated in a demonstration system, a scheduler and 4D descent advisor. The scheduler will assist the controller in selecting efficient landing sequences and assigning conflict-free landing times. The 4D descent advisor will provide various types of trajectory information to assist the controller in achieving accurate landing times selected by the scheduler. Both types of advisors have been studied extensively in real time simulations and now attention is focused on choosing an effective interface between automation tools and the controller. For this purpose several color graphics techniques are being exploited to help the controller visualize the predicted consequences of computer-generated advisories. Furthermore, pop-up command windows and the use of a mouse or trackball to designate a target and select parameters will minimize keyboard entries, thus providing an improved controller interface. Several of these interface features can be seen in the figure.

The plan for the development and evaluation of the demonstration system has been formulated. Real time radar tracks of aircraft available in the Enroute Center Host Computer will be displayed on the Descent Advisor System (DAS) Monitor, which is part of a color graphics workstation (SUN3). Data from NOAA'S experimental wind profile radar system installed in the Denver area will be fed into the workstation computer and processed by the automation algorithm. During the evaluation, the test controller will use the DAS Monitor and the Descent Advisor System to control traffic. A safety controller using his standard ATC Monitor will supervise the traffic flow during the test and take control if necessary. During development, radar tracking and wind profile data are sent from the Denver Center test site to the Advanced Concepts Simulator at Ames. Also, piloted simulator data from the 4D equipped simulator at Langley and the 727 simulator at Ames may be fed into the Advanced Concepts Simulator and used separately or in combinations with the radar data to validate Demonstration System Software and operational techniques.

TECHNICAL CONTACT: H. Erzberger, ARC (415) 694-5425
Bill Nedell, ARC (415) 694-5469

AIR TRAFFIC CONTROL SIMULATION FACILITY

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

In-Flight Monitoring of the Dynamic Stability Levels of Airplanes With Highly Relaxed Static Stability

The objective of this project is to enhance flight safety and efficiency during the initial flight tests of statically unstable airplanes.

Recent improvements in the computational capabilities of the Western Aeronautical Test Range allow significant amount of on-line analysis of flight data. In addition to the traditional stripchart monitoring of time histories, it is now possible to perform a frequency domain analysis of the combined airframe-flight control system by using fast Fourier transform (FFT) techniques and to compare the response of the airplane with that of the simulator while the airplane is in flight in both the frequency and time domains.

The design criteria for the statically highly unstable forward swept wing configuration of the X-29A included minimum levels of gain and phase margins. These margins are normally obtained from the open loop frequency response of systems with feedback control. The enclosed figure depicts schematically how the open-loop frequency response is obtained from pilot generated frequency sweeps, on-line without altering the control system structure. This scheme yields not only the gain and phase margins, but it also allows the frequency response produced by the FFT to be compared with stored predictions from linear analysis. The linear equations of motion are also utilized to produce time history comparison plots in real time showing the differences between the airplane and the linearized version of the simulator.

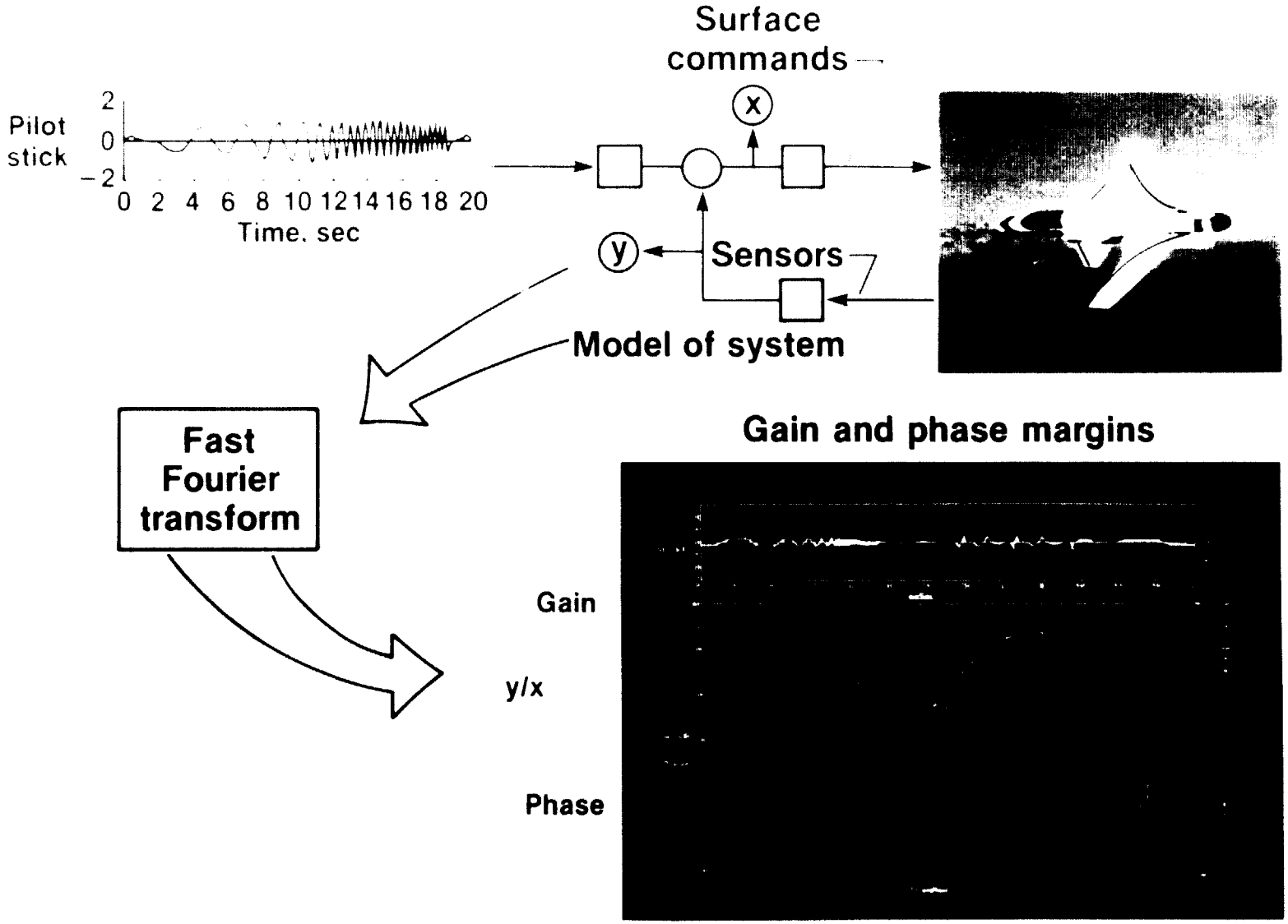
The X-29A continues to fly with static instability levels which are unprecedented for manned airplanes--the static margin is -35 percent at certain flight conditions. The procedure described above allowed the inherently hazardous initial envelope clearance to be conducted in an exceptionally safe manner. Furthermore, the on-line analysis eliminated the postflight data reduction requirement for stability margins. Since envelope clearance became possible at several testpoints in the same flight, it is estimated that the use of the on-line analysis capability resulted in a 30 percent reduction of the time allotted for clearing the X-29A envelope.

To date only the longitudinal open-loop frequency response computation has been implemented on-line. During 1987 the technique will be extended to the lateral-directional axes of the X-29A. Instead of the pilot-generated frequency sweep, a canned input uplinked from a ground-based computer will be used. For the time history comparisons, a full, nonlinear simulation of the test airplane, driven by the telemetered pilot control positions will be utilized, especially whenever significant coupling between the longitudinal and lateral-directional dynamics occurs.

TECHNICAL CONTACT: John T. Bosworth/Joseph Gera, ARC (805) 258-3795

Flight-Determined Frequency Response for Unstable Airframes

NASA



TSRV Experimental System Upgrade Complete

This work is directed toward upgrading the research capabilities of the NASA Langley Boeing 737-100 Transport Systems Research Vehicle (TSRV) to enhance its utility in future aircraft guidance and control and aircraft/air traffic control (ATC) integration flight research.

The upgrade was a two-phase program that began in 1984. Initially two flight-qualified PDP 11/70 computers and the Digital Autonomous Access Communication (DATAC) bus developed by Boeing were installed to replace the original (1974) equivalent equipment. The first phase was completed in 1985. In the second phase, completed July 1987, the original monochromatic 5- by 6-inch CRT displays were replaced by color 8- by 8-inch CRT displays and improved baseline software was installed.

The upgraded system has been checked out and formally validated. The TSRV is now officially ready to begin work on the large backlog of flight research tasks. Limited use of the experimental system in the TIMER aircraft/ATC integration flight tests and in the TSRV demonstrations to senior management has given early hints of its expanded capabilities.

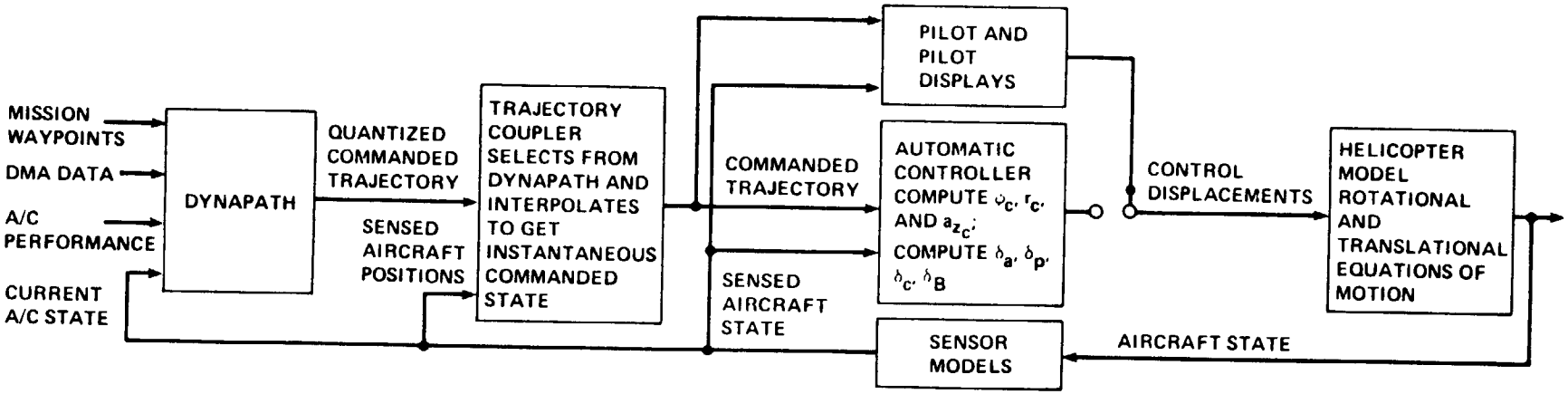
The upgraded experimental system makes the TSRV a unique, premier-class flight research facility that will prove indispensable in evaluating advanced flight management and aircraft/ATC integration concepts.

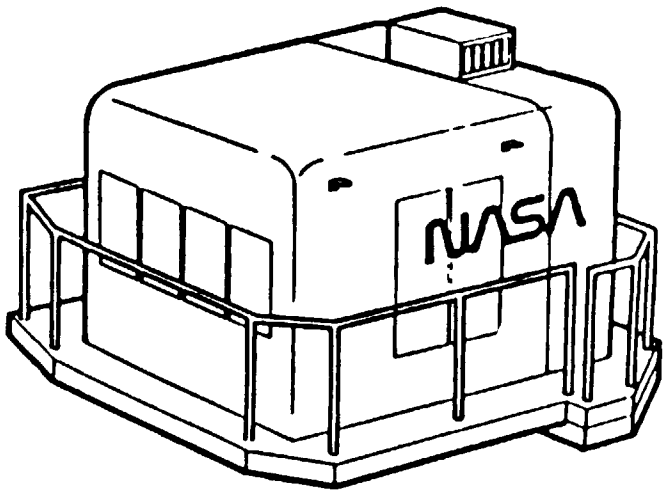
As noted earlier, the first phase of the upgrade included the installation of the DATAC bus. The TSRV is still the only aircraft with DATAC installed, and its extremely successful operation has been a major factor in the pending adoption of a similar bus as the standard for civil aircraft in the 1990's.

Now that the upgraded experimental system is in place several deferred maintenance items will be implemented, including replacing the air data computers and inertial navigation system with an integrated air data/inertial reference system, installing a side-arm controller for the left seat, and replacing the control display units.

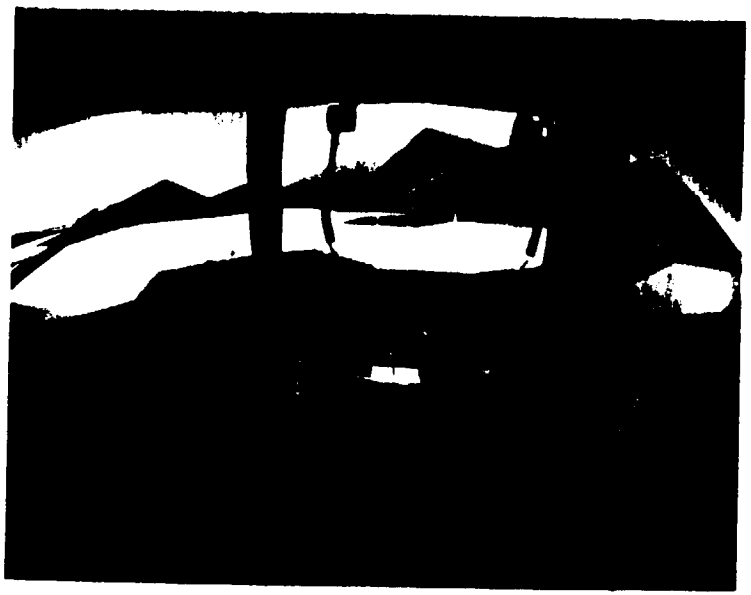
TECHNICAL CONTACT: William E. Howell, LaRC (804) 865-2224

TF/TA SYSTEM BLOCK DIAGRAM





ICAB SIMULATION FACILITY



COCKPIT CONFIGURATION

TSRV Experimental System Upgrade Complete

This work is directed toward upgrading the research capabilities of the NASA Langley Boeing 737-100 Transport Systems Research Vehicle (TSRV) to enhance its utility in future aircraft guidance and control and aircraft/air traffic control (ATC) integration flight research.

The upgrade was a two-phase program that began in 1984. Initially two flight-qualified PDP 11/70 computers and the Digital Autonomous Access Communication (DATAC) bus developed by Boeing were installed to replace the original (1974) equivalent equipment. The first phase was completed in 1985. In the second phase, completed July 1987, the original monochromatic 5- by 6-inch CRT displays were replaced by color 8- by 8-inch CRT displays and improved baseline software was installed.

The upgraded system has been checked out and formally validated. The TSRV is now officially ready to begin work on the large backlog of flight research tasks. Limited use of the experimental system in the TIMER aircraft/ATC integration flight tests and in the TSRV demonstrations to senior management has given early hints of its expanded capabilities.

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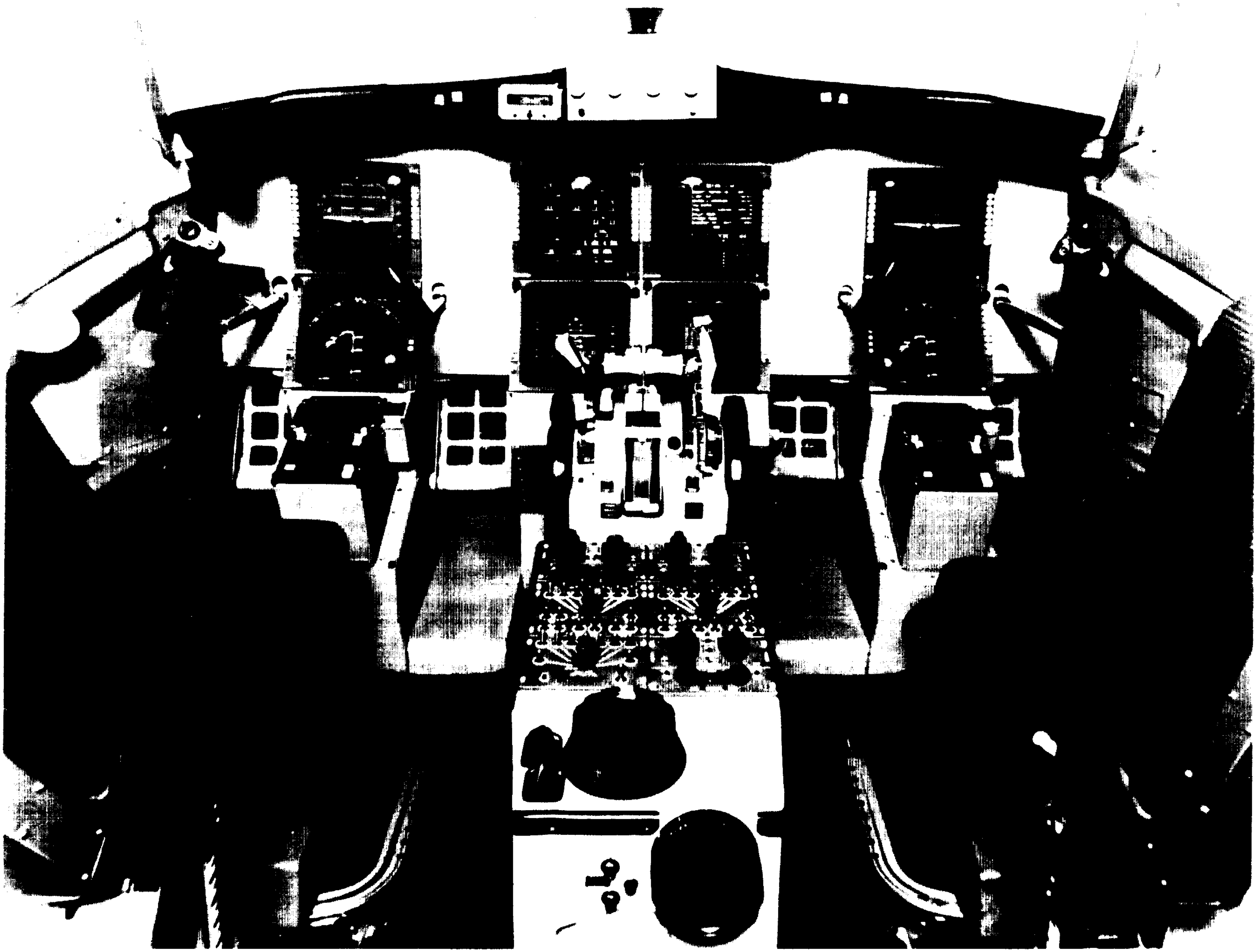
TECHNICAL CONTACT: William E. Howell, LaRC (804) 865-2224

TSRV RESEARCH FLIGHT DECK IN THE ATOPS B737 AIRCRAFT



Developed Message-Exchange Concept Application to Air-Ground Data Link

The planned modernization of the U.S. National Airspace System (NAS) includes the development and use of digital data link capability as a means of exchanging information between aircraft and ground-based facilities. The objective of this contractual research effort with the MITRE Corporation was to develop an ATC-message-exchange concept for data link operations by transport aircraft.

Radio-telephone voice-communication practices in the present day airspace system were analyzed through review of transcripts, FAA handbooks and manuals, and consultation with experienced pilots and controllers. Data link message-exchange design goals based on these results were established and used to develop a methodology for air-ground message exchange with emphasis on flight deck requirements. Representative messages were placed in an operational scenario comprising an airline flight from Boston to Denver via Chicago in order to visualize and assess how data link operations could be used for ATC-message exchange.

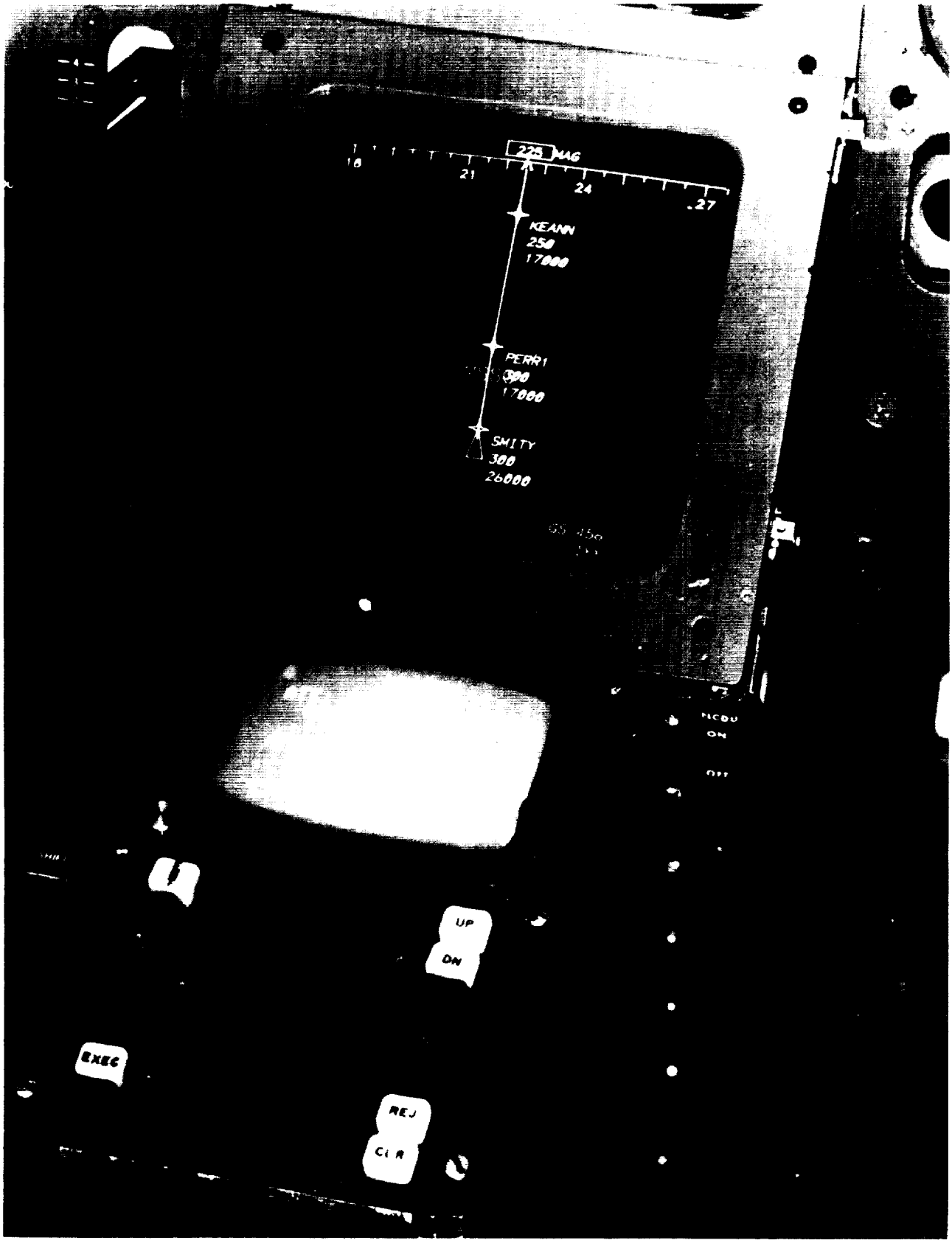
A concept for data link ATC-message exchange in an operational transport flight deck was developed. The concept, as shown in the attached figure, included crew procedures and operational protocols, as well as a functional partitioning of the proposed airborne Communication Management System (CMS) into a message handler, a buffer, a crew interface which included a conventional radio-telephone, a five-part message file, and a taxonomized set of messages for handling the most common ATC clearance negotiations. Feasibility of the concept was shown by applying it in a paper and pencil study of a transport aircraft flight from Boston to Denver via Chicago.

A basis for expanding the Langley-derived aircrew-ATC data link message exchange concept to provide improved airborne capabilities in composing and managing messages has been established. Also, a set of messages of reasonable scope, arranged in an appropriate taxonomy for implementation in such a concept, has been assembled.

To further develop the data-link ATC-message-exchange concept, subsequent in-house piloted simulation tests will integrate the recommendations of this study with guidelines resulting from related in-house investigations. A follow-on contracted investigation is expected to explore ATC functions to support 4D traffic control, as well as present day operations incorporating data-link ATC-message exchange.

TECHNICAL CONTACT: Marvin C. Waller, LaRC (804) 865-3621

ATC MESSAGE EXAMPLES DISPLAYED ON CDU



Controls and Guidance - Space

The Space Controls and Guidance Research and Technology Program is directed toward enabling the next generation of space transportation systems, large future spacecraft and space systems such as the growth Space Station to have large communication antennas and high precision segmented reflector astrophysical telescopes. The new generation of transportation vehicles has demanding requirements to provide for an order of magnitude reduction in cost as well as an increase in capability. The future orbital facilities have demanding control requirements for pointing and stabilization, momentum management, build-up and growth accommodation, and disturbance management.

To address these advanced requirements, the research and technology program for Space Controls and Guidance is designed to provide the generic technology base to support the implementation of advanced guidance, navigation, and control (GN&C). This technology has the capability to provide for a large reduction in both the number of people who plan and generate the mission software and the people necessary later to provide for mission control. The early incorporation of this technology into the system studies for new vehicles will also positively impact vehicle design concepts to insure the full realization of potential benefits.

The area of computational controls will be stressed in order to develop cost effective, high speed, high fidelity control system simulation and analysis and synthesis tools. The thrust of this work will be to develop methods and software to enable analysis and real-time hardware-in-the-loop simulation of complex spacecraft for control design certification. This capability has the potential of achieving a 4 order-of-magnitude improvement in the ability to rapidly analyze and simulate control systems for very large complex spacecraft.

To address future orbital facilities requirements, an advanced technology program is underway in system identification, distributed control, integrated controls/structures design methods, and advanced sensors and actuators. Because the behavior of large, light weight per unit area deployable/assembled spacecraft is greatly influenced by the ground environment (principally gravity), the testing and verification activity is both ground- and space-based.

PROGRAM MANAGER: John D. DiBattista
NASA/OAST/RC
Washington, DC 20546
(202) 453-2743

- - AIPS - -
Advanced Information Processing System

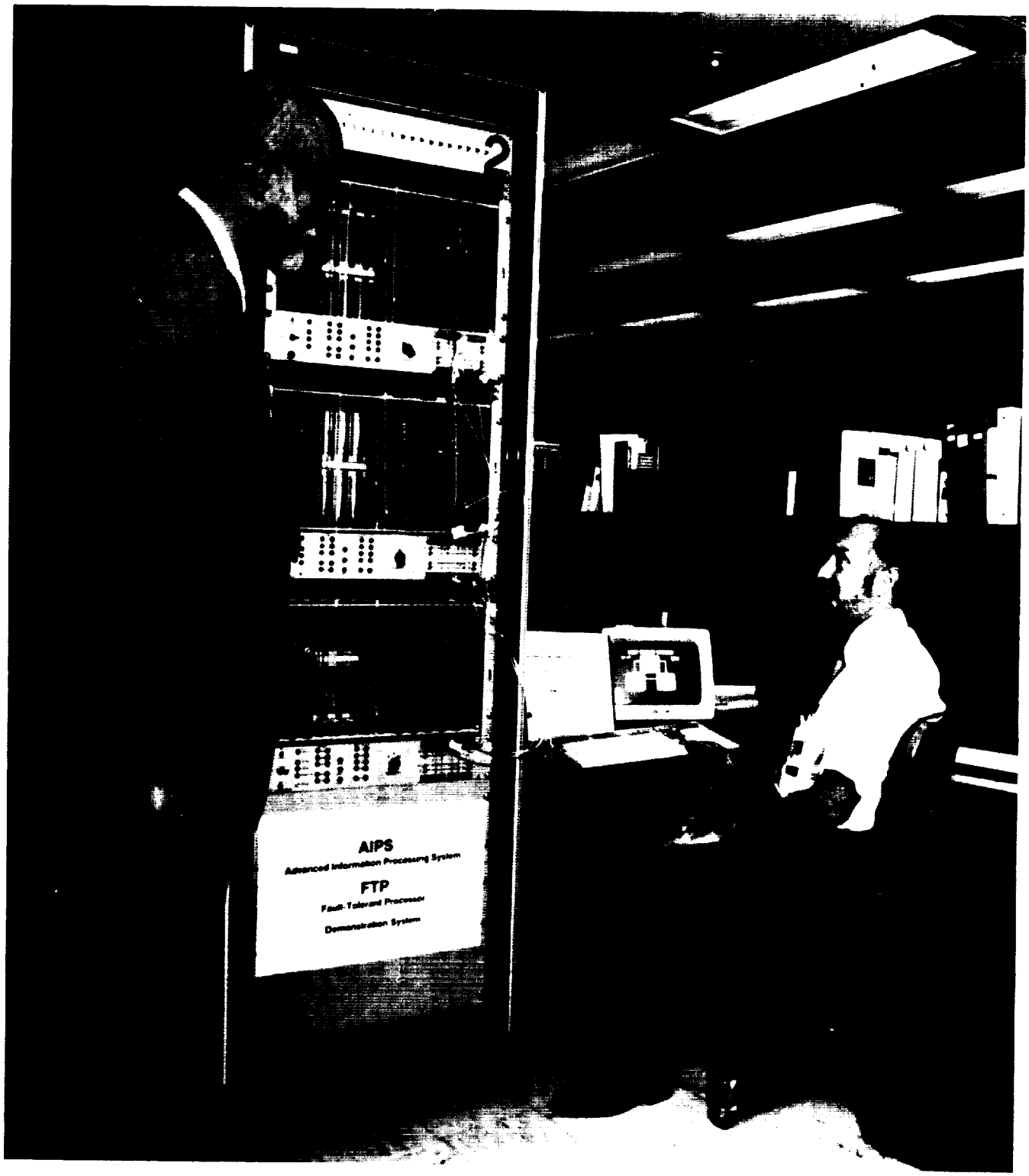
The Advanced Information Processing System (AIPS) was a generic study to develop requirements and a proof-of-concept demonstration system that addressed fault tolerance at a system level. The study included processors, data bus networks, mass memory interfaces, and software operating systems and system support software. There was an initial phase that developed requirements for a cross section of existing and advanced NASA programs in both aeronautic and aerospace disciplines. The second phase included detailed analysis and preliminary design for the proof-of-concept system. There were also spin-off new technology proposals that were identified during phase one as a result of preliminary analysis and design. These new technology initiative proposals were not considered as new tasks for the AIPS project; they became inputs to parallel supporting development efforts at various NASA Centers.

Phase 3 was devoted to design, fabrication, and testing of the proof-of-concept demo system. This phase resulted in significant advances in software state of technology for the Ada language and established guidelines which would be followed in subsequent years by the Space Station Program. The demo system required development of a software environment to support generation of software for the processors. Here again, this effort was a pathfinder for the Space Station and defined characteristics required by the Software Support Environment (SSE). Specific areas of concern included compiler efficiency, software tool integration, test programs, and flight processor monitoring techniques. These issues became directed tasks for study and resolution by the SSE contractor.

One of the triple redundant processors from the proof-of-concept demo system is shown in the photograph. This unit will be used as the Johnson Space Center to support studies in a number of advanced programs. These include the Space Station, Crew Emergency Return Vehicle (CERV), Mars Lander System and Shuttle II. This processor is also scheduled to support the evaluation of real time control programs written in the Ada Language.

TECHNICAL CONTACT: Ed Cheevers, JSC, (713) 483-8225

ADVANCED INFORMATION PROCESSING SYSTEM



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Fiber Optic Rotation Sensor (FORS)

The Fiber Optic Rotation Sensor (FORS) task objective is to develop a 10 year plus lifetime, low cost, lightweight, highly reliable and high performance (navigation-grade) optical gyroscope.

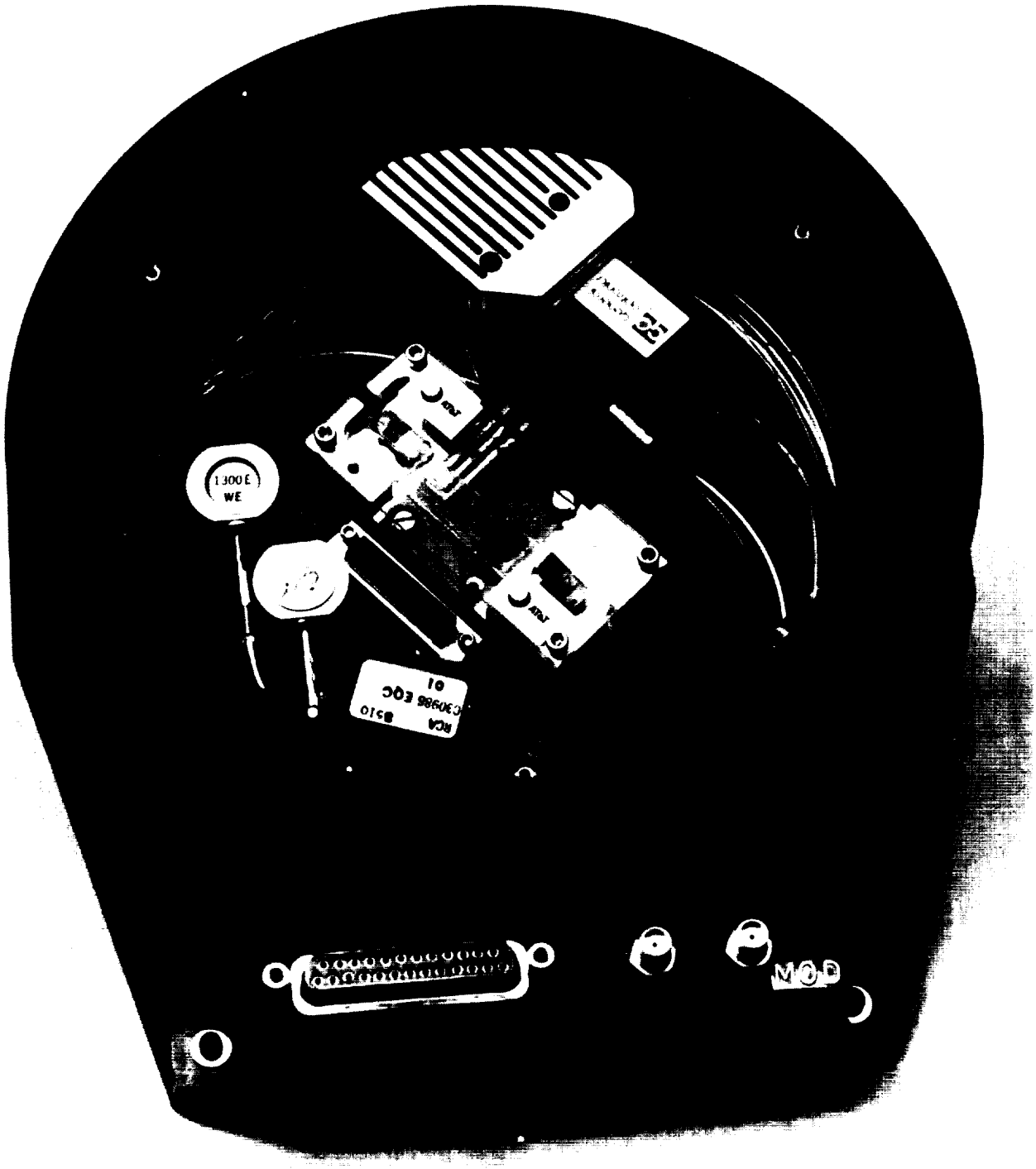
An advanced optical circuit, using semiconductor lasers, fiber optic waveguides and integrated optical waveguide circuits for operation at 1.3 micron wavelength, will perform all key signal processing functions. The design, as illustrated, features a closed-loop phase control which provides for operation over a large dynamic range of rotation rates with the output signal being a high precision position angle.

An intermediate 3-component Integrated Optics (IO) chip has been successfully packaged in a brassboard configuration gyro and is undergoing extensive evaluation. This is the first gyro of this kind in the USA. Preliminary performance tests have shown the gyro running very near or at the theoretical limit for this configuration with a random walk performance of 10^{-2} deg/ hr. This represents the accomplishment of a major milestone of the FORS program in that it gives good assurance that the final eight component IO chips will perform as required.

A more advanced intermediate IO chip, one with five components, has been designed, fabricated and is now under test at AT&T Bell Labs. This chip will be delivered to JPL by October 1987 and will be assembled in an advanced fiber gyro brassboard using polarization-preserving fiber.

TECHNICAL CONTACT: Ramon P. De Paula, JPL, (818) 354-4455
Fernando A. Tolivar, JPL, (818) 354-6215

FIBER OPTIC ROTATION SENSOR (FORS)



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Large Space Structure Control Technology

Performance requirements for a system drive the control design. System requirements, which demand high performance, necessitate that a high performance controller be effected. As control synthesis is very dependent upon the system, it is necessary that a mathematical model of the system be developed. The analysis of the mathematical model gives insight into the behavior of the system. Naturally, the accuracy of the information obtained depends upon how well the system has been mathematically modeled. The performance requirements also dictate the fidelity required of the modeling process. So the accuracy of the model determines the merit of the control synthesis which in turn defines the system's performance. Within the design methodology the system performance, which is enforced by specified requirements, enforces modeling accuracy constraints and the modeling accuracy determines the limits of performance which is achievable with a given control design.

The translation of the modeling and control synthesis into a Large Space Structure Control Technology program is the objective of this research. Since two items which are dependent upon one another through performance requirements are addressed, the program tasks are divided into two distinct paths. The tasks are Multibody Modeling and Verification (MMV) and Advanced Control Evaluation for Structures (ACES).

The main objectives of the Multibody Modeling and Verification effort are (1) to develop a user friendly computer analysis tool which has the following: nonlinear modeling of ring topologies of flexible bodies, selectable sensor and effector components, classical and modern control methodologies, open and closed loop model reduction algorithms, orbital dynamics capabilities, thermal-mechanical interaction, mass/inertial flow, geometric stiffness; and (2) to verify the component modal synthesis methods, which are used in the aforementioned computer tools, on an actual Large Space Structure with multibody characteristics.

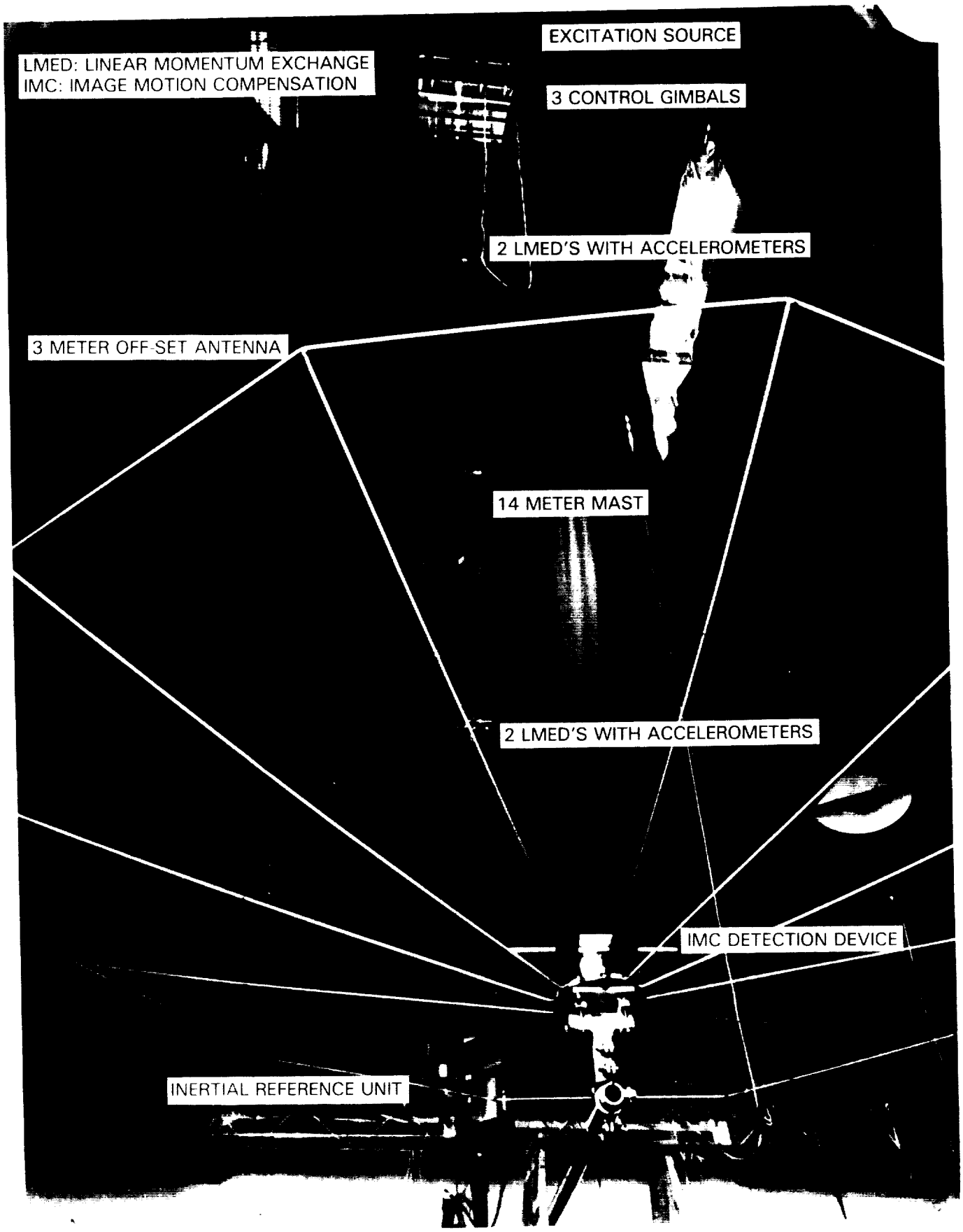
The basic objectives of the ACES programs are to develop ground facilities in which advanced control system methodologies can be developed, tested, and verified. In addition, the course of the new facility thrust must be directed towards future NASA projects so that the advanced control concepts and their appropriate software packages can be dynamically verified to ensure on-orbit success.

Currently, the Single Structure Control Lab is functional and has been used to demonstrate several control techniques that were developed for Large Space Structures (see figure 1).

To address future NASA projects, additional ground facilities will be developed: (1) Pinhole/Occulater Facility Lab; (2) Multiple Payload Pointing Mount Facility Lab; (3) Unobtrusive Sensor and Effector Lab; (4) Intelligent Structures and Robot Enhancement Facility Lab; and (5) Control of Optical Trains Lab. Several advanced control concepts will be used as potential candidates to solve the dynamic/control problems which are encountered in the aforementioned labs.

TECHNICAL CONTACT: Henry B. Waites, MSFC (205) 544-1441

THE CURRENT LARGE SPACE STRUCTURE CONTROL TECHNOLOGY TEST CONFIGURATION



Development Of The Spacecraft Control Laboratory Experiment (SCOLE) Facility

A modeling and control design challenge for flexible space structures has been presented to the technical community by NASA and the IEEE. The Spacecraft Control Laboratory Experiment was constructed to provide a physical test bed for the investigation and validation of control techniques developed in response to the design challenge. The control problems to be studied are slewing maneuvers and pointing operations.

The design challenge was presented in two parts. The first part is to design control laws using a given set of sensors and actuators for a mathematical model of a large antenna attached to the space shuttle by a long flexible mast. The second part is to implement the control laws on a laboratory representation of the structural configuration. This highlight concerns progress on the second part.

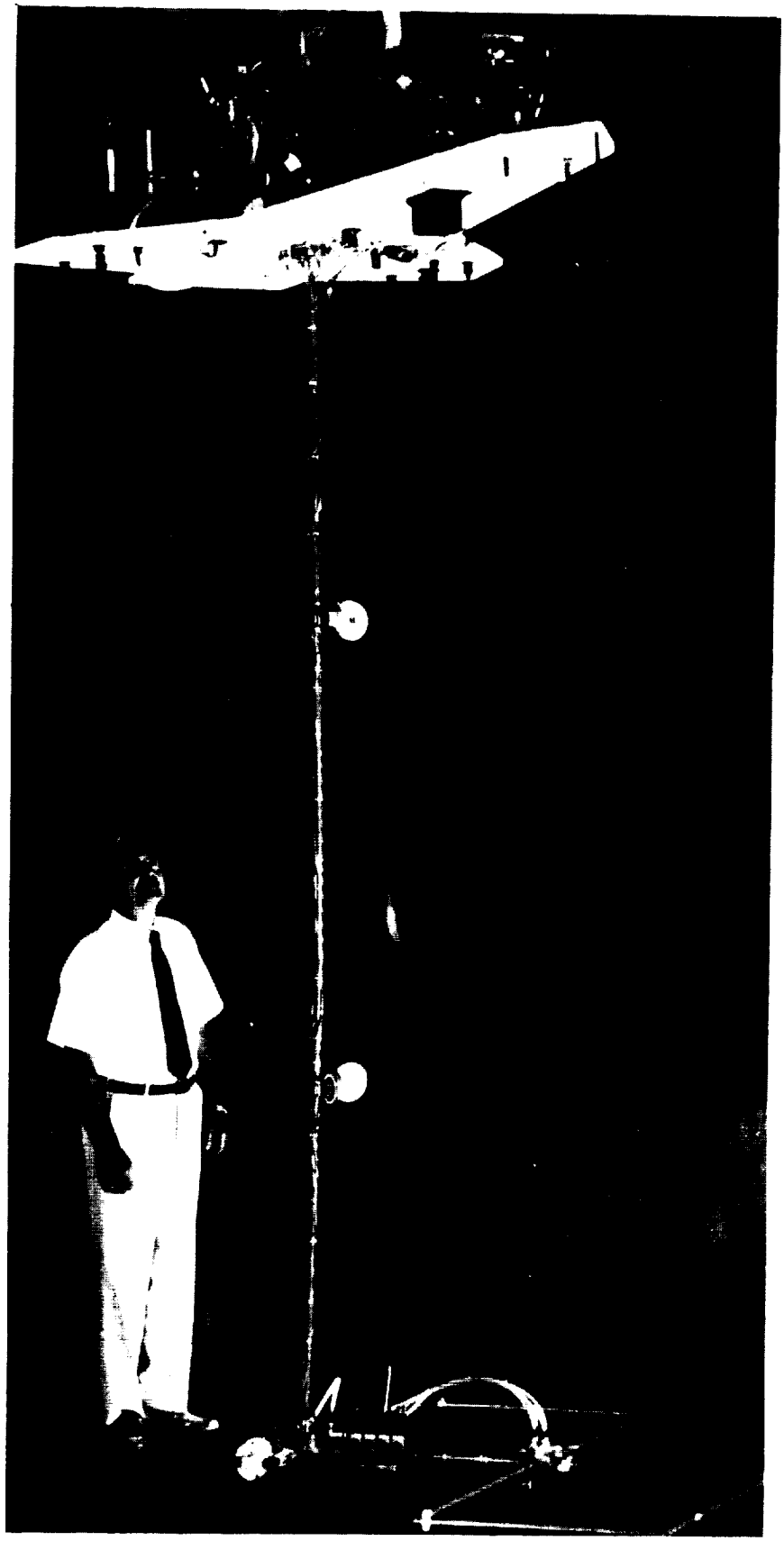
The SCOLE laboratory facility developed in response to the second part of the design challenge has been made operational. The facility is documented in a NASA Quick-Release Technical Memorandum entitled "Description of the Spacecraft Control Laboratory Experiment (SCOLE) Facility." This publication gives structural and component descriptions sufficient for modelling and the design of control laws for the laboratory configuration.

This publication will be distributed to a number of researchers who are interested in testing their control schemes on the facility. The SCOLE is the first generally accessible facility for testing modelling and control techniques on a three-dimensional structure with a realistic control objective. It is expected that the bulk of the software development and control law testing will be carried out from the principle investigators home site through the remote computer access capability of the facility.

The document will be maintained as "user's guide" so that outside investigators can use the facility to test and improve their design and analysis methodologies. NASA personnel will work closely with the investigators to assist them in implementing their techniques on this "real-world" problem.

TECHNICAL CONTACT: Jeffrey Williams, LaRC (804) 865-4591

SPACE CRAFT CONTROL
LABORATORY EXPERIMENT TEST ARTICLE



Autonomous Adaptive Control Subsystem Development

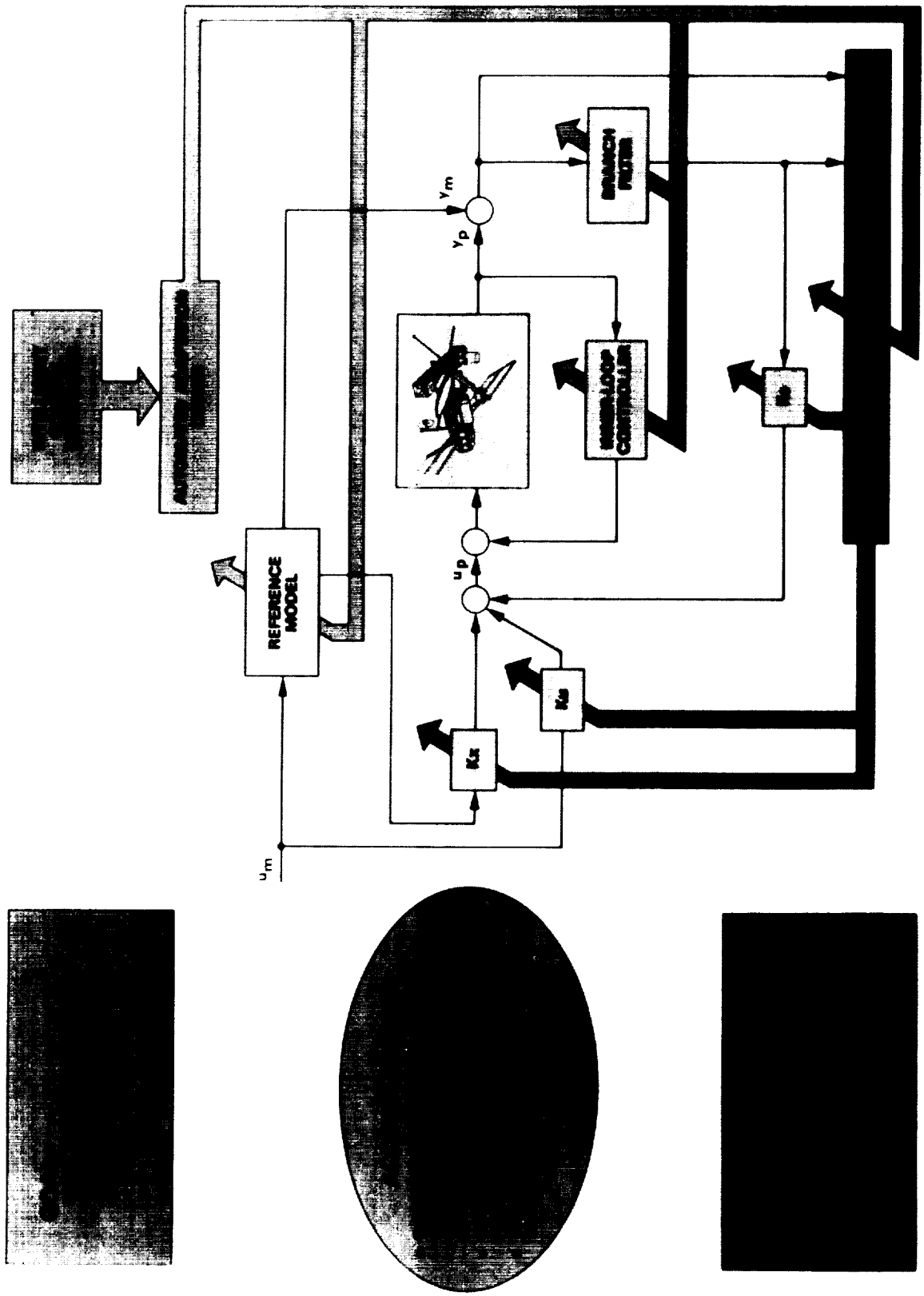
The research objective is to develop an autonomous adaptive control subsystem for application to emerging space systems including future large flexible structures and advanced space transportation vehicles. The overall approach is to develop high level autonomous control technology and advanced adaptive control techniques, and integrate these into a controller design which is robust to gross system changes, such as large parameter jumps, hardware failures, model-order variations, anomalies, operational disturbances and changes in mission objectives, as well as to local phenomena including drifting parameters, model uncertainties, and environmental disturbances. This concept will provide robust stabilization and control with enhanced performance for future space systems.

Accomplishments in FY87 include development of the branch filter concept which allows filtering of the output error without introducing phase lag into the adaptive loop. Thus the measurement noise can be effectively suppressed while insuring global stability of the adaptive algorithm. Also, the bound-optimal design concept was developed for the problem of designing adaptive control systems to meet performance specifications. The basic approach involves using the best available information of the plant, to choose design weightngs that optimize the performance with respect to bounds on the nonlinear system response as provided by Lyapunov analysis, dominant mode analysis, asymptotic/averaging analysis, etc. Moreover, an analysis has been performed which gives guidelines for stable adaptive control synthesis by using inner-loop compensation in the presence of rigid body dynamics. The first of a series of control technology validation experiments have been developed for the large space structure ground experiment facility recently completed at JPL. The experimental data and post experiment analysis results are expected by the end of FY87. The experience gained here and those from the case studies conducted previously have been employed in the development of on-board computational requirement.

The direction of research and development for FY88 include the development of theorems for bounding the trajectories induced by an adaptive controller and utilizing such bounds to establish optimization problems whose solution would lead to performance optimal adaptive designs. Investigation will begin on the adaptive regulator problem and subsequently be extended to the more complex tracking and branch filter designs. Work in the area of intelligent control supervisory subsystem development will focus on the integration of both symbolic decision rules and numerical algorithms. This will lead to the demonstration of high-level adaptation using an expert system shell. The technology evaluation efforts will be extended to Phase II and III. In Phase II, the experiments will demonstrate the MIMO adaptive regulation augmented by rib root sensors and actuators. The results will be analyzed and compared with those of Phase I. In Phase III, the robustness of the adaptive control system to actuator saturation/delay will be studied.

TECHNICAL CONTACT: Shyh J. (Don) Wang, JPL (818) 354-7288
Fernando Tolivar, JPL (818) 354-6215

AUTONOMOUS ADAPTIVE CONTROL TECHNOLOGY



Spatial High Accuracy Position Encoding Sensor (SHAPES)

The objective of this task is to develop a control sensor able to make simultaneous 3-dimensional position measurements of multiple (up to 50) targets. These measurements need to be made with sub-millimeter accuracy and with a sufficient data bandwidth for system identification, shape and vibration control of large space structures.

SHAPES, which combines optical angle measurements with time-of-flight range measurements, has the special capability of dynamically tracking many targets simultaneously. The sensor makes use of laser diodes, charge coupled device (CCD) imaging detectors and a picosecond-resolution streak tube to provide 3-D position sensing of retro-reflector targets. Multi-target tracking capability is required to determine both static and dynamic in-orbit characteristics of large antennas, platforms, and the Space Station. SHAPES measurements can be used to check structural alignment and overall geometry during each assembly phase of the Space Station to verify correct assembly. In-flight structural dynamics data obtained by SHAPES can be used to verify the accuracy of the models that were used for selecting the control parameters for the attitude control system (ACS) and thereby provide confidence in the safe operation of the Space Station after each assembly phase or other major structural modification. The SHAPES technology could also be used to determine absolute payload pointing/position from navigational base reference position measurements. In addition, a derivative of SHAPES (which may use an opto-electronics detector in place of the streak tube) could be used as a rendezvous and docking sensor at ranges up to 40 km. A spin-off of the SHAPES measurement technology task is now being developed by the Space Tracking and Data Systems office for application to large NASA ground based antennas.

The successful FY86 SHAPES demonstration of simultaneous ranging to eight moving targets with a measurement resolution of 25 microns was documented on a video tape which is available from the author. SHAPES has been modified this FY to provide simultaneously ranging to 16 moving targets at a data update rate of ten measurements per second. The improved capability has been integrated into the joint NASA/AFRPL Control Technology Validation experiment to provide range measurements. During 1987, the design requirements for a 3-D SHAPES were identified and a preliminary design concept selected. The 3-D design will incorporate capability for increased target number, data readout rate, and sensor FOV. It will combine two-phase and dual-frequency operation to eliminate some measurement ambiguities associated with the streak tube ranging technique.

TECHNICAL CONTACT: Fernando Tolivar, JPL, (818) 354-6215
Noble Nerheim, JPL, (818) 354-2547

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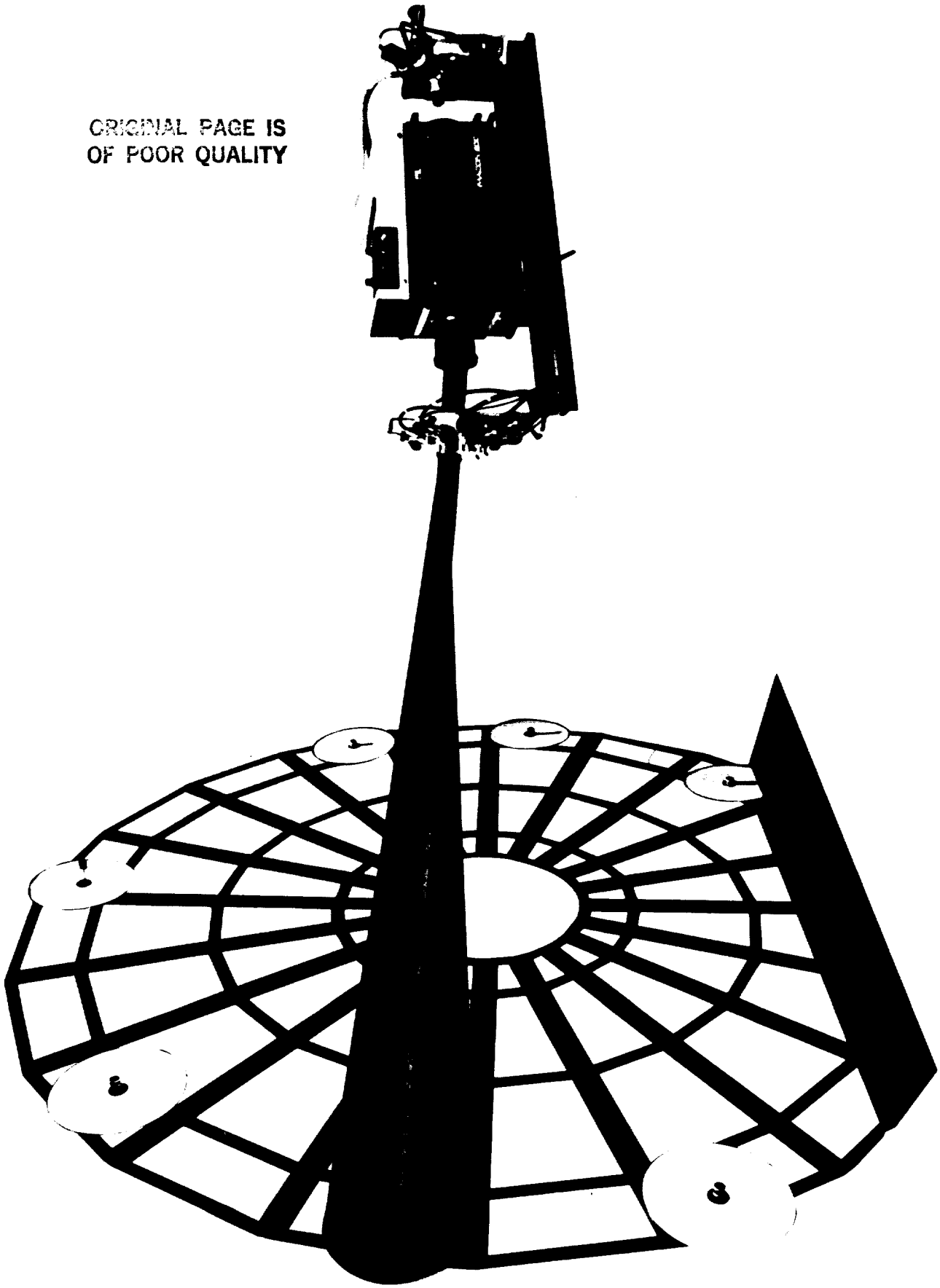
SHAPES TECHNOLOGY DEMONSTRATION



Optimal Trajectories for Future Aeromaneuvering Vehicles

The objectives of this research are to determine the most cost-effective trajectories that meet mission objectives of future aeromaneuvering vehicles such as AOTV, Shuttle II, and Aerospace Plane.

The approach is to use sequential gradient-restoration optimization algorithm developed over many years at Rice University to examine the characteristics of trajectories that minimize a variety of performance measures within the framework of either classical optimal control or minimax optimal control, in order to determine the trajectories with the best compromise between various conflicting requirements.

A major milestone has been the development of the class of nearly-grazing trajectories. These trajectories achieve an excellent compromise between energy requirements and heating rate requirements for aeroassisted orbital transfer with plane change.

Nearly-grazing trajectories minimize the time integral of the square of the flight path angle. This is a clear geometric objective, and should be easy to implement in the form of a practical, onboard guidance law.

It is planned to apply the techniques developed to various types of hypervelocity vehicles such as AOTV, Shuttle II, and Aerospace Plane.

TECHNICAL CONTACT: Lincoln Wood, JPL, (818) 354-3137

OPTIMAL TRAJECTORIES FOR AEROASSISTED ORBITAL TRANSFER

K. D. Mease (JPL) and A. Miele (Rice University)

Results for $\Delta i = 30$ deg,
Initial Orbit Radius/Final Orbit Radius $\cong 2.0$,
Final Orbit Radius/Radius of Outer Edge of Atmosphere $\cong 1.0$

Transfer Mode	Propulsive	Aeroassisted			
Performance Index	Minimum Energy	Minimum Energy	Nearly-Grazing	Minimum Peak Heating Rate	Units
Characteristic Velocity	3788	1919	1966	2143	$m\ sec^{-1}$
Atmospheric Flight Time	0	23	20	15	min
Peak Heating Rate	0	126	95	71	$W\ cm^{-2}$

Conclusions:

- Aeroassisted Transfers Require Substantially Lower Characteristic Velocities (i.e., Less Propellant)
- Nearly-Grazing Transfer is Nice Compromise Between Minimum Energy and Minimum Peak Heating Rate Aeroassisted Transfers

Attitude Control System Synthesis for the Hoop/Column Antenna Using the LQG/LTR Method

The objective of this research is to investigate the applicability of the Linear-Quadratic-Gaussian (LQG)/Loop-Transfer-Recovery (LTR) multivariable frequency-domain approach, and its applicability to large space structures (LSS) control problems.

The approach taken was to study the theoretical basis for the method and modify for application to LSS, combine existing LQG software (ORACLS) with newly developed multivariable frequency domain analysis software (FREQ) to produce a hybrid time/frequency domain computer-aided design, and apply it to a realistic mathematical model of the 122m Hoop/Column antenna.

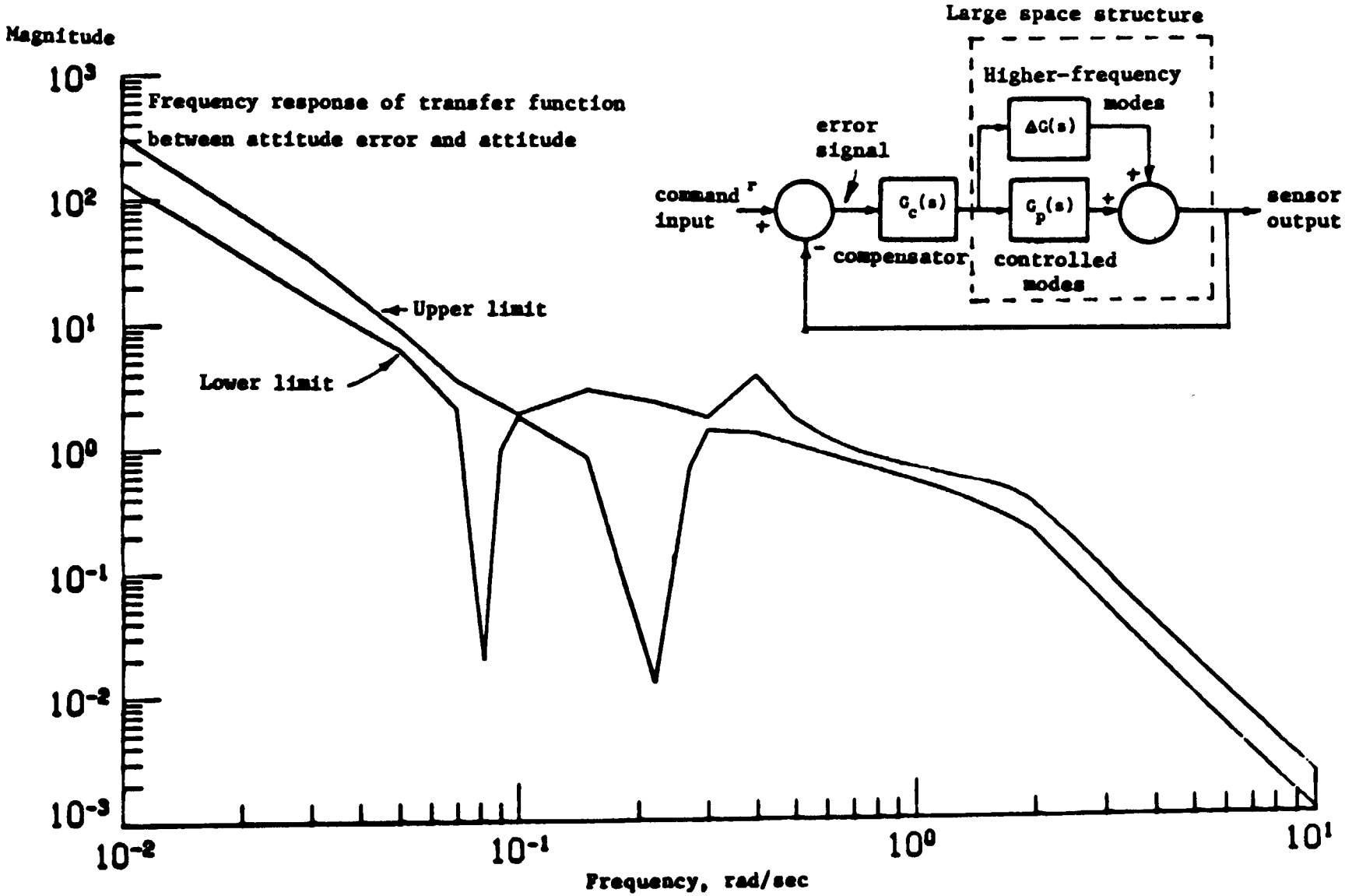
A compensator (donated by G_c on the graphic) for a Hoop/Column design model (G_p) was obtained which had sufficient bandwidth for attitude control and simultaneously maintained stability robustness against unmodelled dynamics (.G) of the higher-frequency modes. The maximum (.) and minimum (.) singular value band (a measure of the loop gain) illustrates that a chosen 0.1 rad/sec bandwidth was obtained using this method, although some performance deterioration (indicated by dips in .) was unavoidable because of the system characteristics (i.e., transmission zeroes). Two papers describing this study have been accepted for the AIAA Guidance, Navigation, and Control and for the Journal of Guidance, Control, and Dynamics.

The significance of this work is the importance of hybrid robust control design algorithms for large space structures problems. The LQG/LTR method was found to give an acceptable design, although it required high loop gains which may limit its application to flexible systems. It was also found to be sensitive to the presence of transmission zeroes inherent to finite-element models.

Efforts are being made to improve the LQG/LTR methodology. New hybrid approaches based on stable factorization techniques are being sought.

TECHNICAL CONTACT: S. M. Joshi, E. S. Armstrong, LaRC (804) 865-4591

LOOP-GAIN FOR THE FINAL DESIGN



On-Orbit System Identification

The objective of this research is to develop methodology, techniques and algorithms required to perform in-flight control dynamics identification and characterization of key structural and environmental parameters.

The approach taken was to develop and combine state-of-the-art linear and non-linear estimation techniques with realistic on-orbit experimentation and application procedures.

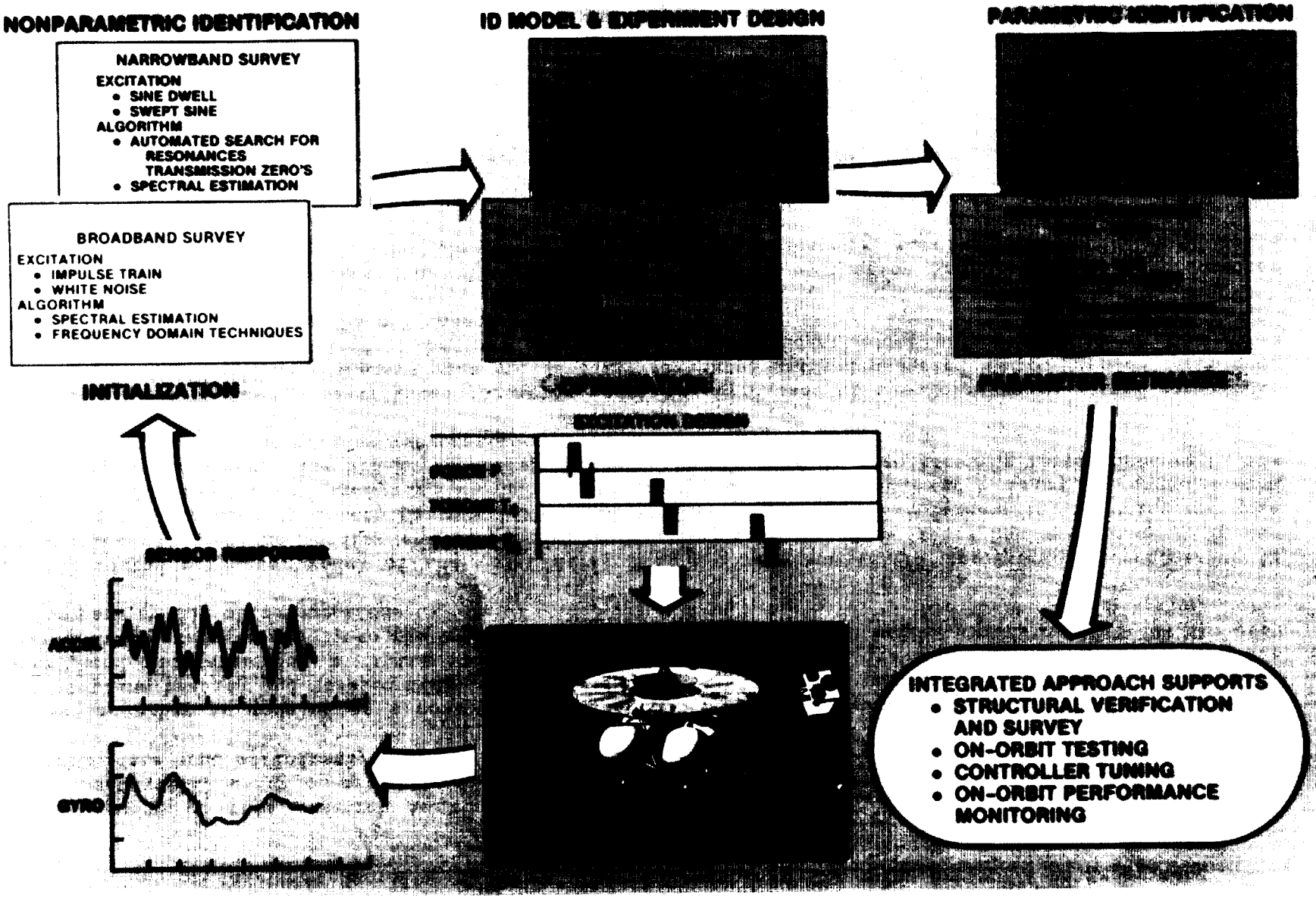
Advanced Maximum Likelihood Estimation (MLE) methodology as a practical tool for system identification of Large Space Structures (LSS); demonstrated sequenced multidirectional thruster firing for providing on-orbit excitation design; demonstrated system identifiability of modal frequencies under constrained excitation and sensing; analyzed dependence of successful on-orbit identification on experiment design and initial parameter uncertainty.

The significance of this work enables on-orbit testing of LSS under operational constraints. The identification of modal frequencies provides information useful for structure verification, adaptive controller tuning, active vibration control, payload pointing jitter suppression, and vehicle stabilization.

Future plans are to develop actuation and sensing strategies which extract parameter information efficiently (i.e., optimal design of experiment) given a constrained on-orbit configuration and testing environment; focus on the identification of parameters which directly support on-board controllers; develop end-to-end methodology for synergistic use of frequency and time domain identification techniques.

TECHNICAL CONTACT: Edward Mettler, JPL, (818) 354-2071
Fernando Tolivar, JPL, (818) 354-6215

INTEGRATED SYSTEM IDENTIFICATION APPROACH



Distributed Parameter Modeling of The Structural Dynamics of The Solar Array Flight Experiment

The objective of this research is to create a Distributed Parameter Model of the Solar Array Flight Experiment (SAFE) using on-orbit data and Maximum Likelihood Estimation, and to perform the analysis of on-orbit data most efficiently.

The solar array is modeled as a continuous, taut membrane using partial differential equations for the out-of-plane bending and torsion modes. A modified Newton-Raphson technique is used to determine Maximum Likelihood estimates for a finite version of the model. Results are used to extrapolate, via the distributed parameter model, to the higher modes. A CDC Cyber 205 with memory extension (VPS-32) was used to compare speeds of computation.

A distributed parameter model of the Solar Array Flight Experiment (SAFE) structure was successful in predicting out-of-plane bending and torsion modal characteristics. A modified Newton-Raphson technique was successfully used to obtain Maximum Likelihood estimates for the modal frequencies, damping and mode shapes. The results of analyzing on-orbit data compared closely with those using an eigne system realization technique. The VPS-32 Supercomputer was determined to be significantly faster because of its parallel processors and program vectorization.

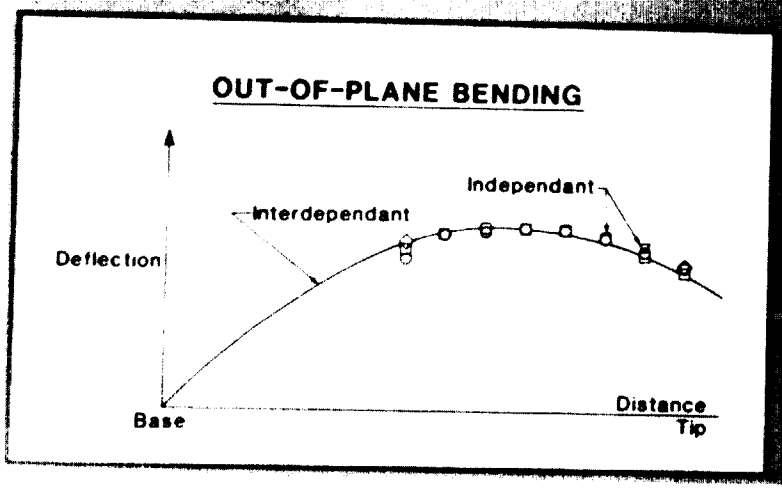
This is the first time a distributed parameter model has been made of the Solar Array Flight Experiment and for which its model parameters were successfully estimated using a modified Newton-Raphson technique. The results are most significant because the number of independent model parameters can be kept to a manageable number by using PDE/MLE modeling.

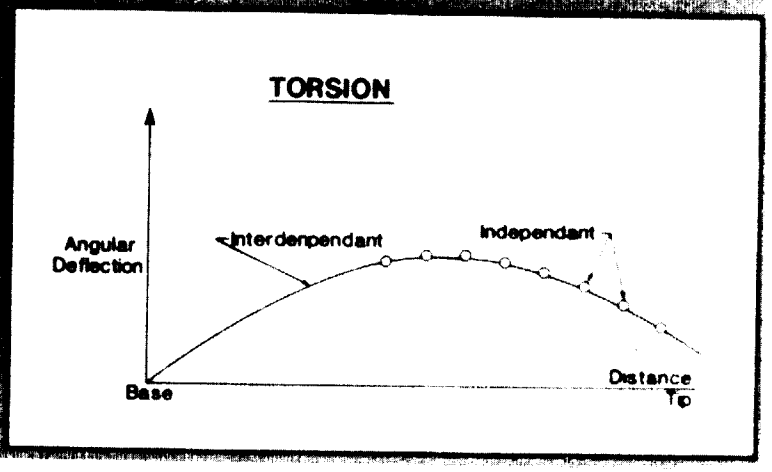
Distributed parameter modeling coupled with Maximum Likelihood estimation and the VPS-32 Supercomputer will enable the modeling of the structural dynamics of increasingly complex structures, i.e. Space Station.

TECHNICAL CONTACT: Lawrence W. Taylor, Jr./James L. Williams, LaRC (804) 865-4591

PARAMETER IDENTIFICATION ON SOLAR ARRAY

MODE SHAPES





Data Systems

The Data Systems Program consists of research and technology devoted to controlling, processing, storing, manipulating, and analyzing space-derived data. The objectives of the program are to provide the technology advancements needed to enable affordable utilization of space-derived data, to increase substantially the capability for future missions of on-board processing and recording and to provide high speed and high volume computational systems anticipated for missions such as the evolutionary Space Station and Earth Observing System.

The Data Systems Program supports fundamental research in such areas as laser diodes, supports work to select and provide the appropriate on-board processor technology for future NASA missions, and also supports the development of two flight processors with special architectures. The ongoing support for solid state laser research leads directly to the development of a 9 laser diode array which is used in the Optical Disk Recorder. The laser research is also focusing some effort applicable to Space Station data handling applications. These devices are being developed to handle both the 300 Mbit/sec basic data rate and the much higher rates needed to support networking and computer internal communications. Complementary research is being supported to characterize the fundamental performance and properties of various alternative networking.

NASA missions require processors that will work very reliably in the space environment. Computer systems for missions in polar orbit and some planetary missions must operate reliably in high radiation environments. The Data Systems Program capitalizes on the dramatic advances in electronics, computer systems, and software which are occurring in both the public and private sectors. It fosters and leads the development of technologies required to meet NASA's unique data systems needs. NASA technical expertise is being applied in cooperative arrangements with DOD, and products from the DOD VHSIC program, and other DOD developments, are being assembled into processors for test and evaluation.

The Advanced Digital SAR Processor includes a special architecture and algorithms to process SAR data. The unit will have a compute rate of 6000 Megaflops per second. The Massively Parallel Processor (MPP) is being used for ground processing of space image data, SAR data, and spectral analysis. The MPP utilizes 16,384 processors. The research applications developed on the MPP have verified the expected tremendous computational power of the MPP for the target applications. Researchers outside of NASA in several universities, research centers, and industry have been provided access to the MPP to gain an understanding of the capabilities of the MPP and have applied these unique resources to a broad range of computational problems.

Future objectives through the Civil Space Technology Initiative in High Rate/High Capacity Data include data system architectural studies for new space initiatives, significant advances in technologies and capabilities for on-board image processing, data compression, high volume block access storage, data networks, spectrometry and adaptive sensor control.

PROGRAM MANAGER: Dr. Paul H. Smith
NASA/OAST/RC
Washington, DC 20546

Very High Speed Integrated Circuit Multiprocessor Technology

This program will co-develop, with DoD, VHSIC general purpose processor technology for potential insertion into NASA 1990+ space missions such as Space Station, Earth Observatory System, and aerospace transportation systems to provide enhanced performance, variable fault tolerance, decreased size and weight, and ease of concurrent operation for a wide variety of future embedded applications. The leveraged nature of this program enables NASA to cost-effectively take advantage of major component developments, VHSIC standards, and future parts availability.

NASA needs advanced onboard general purpose computing capability for increased throughput, functional performance, and reliability; selectable fault tolerance; and versatile self-testability. Future missions will require multiprocessor systems to accommodate projected throughput requirements. Selectable fault tolerance facilitates a wide range of mission fault tolerance requirements with the same flight qualified VHSIC hardware. The DOD-developed VHSIC Phase I technology has matured to a level where system components can be developed which are suitable for advanced multiprocessor systems.

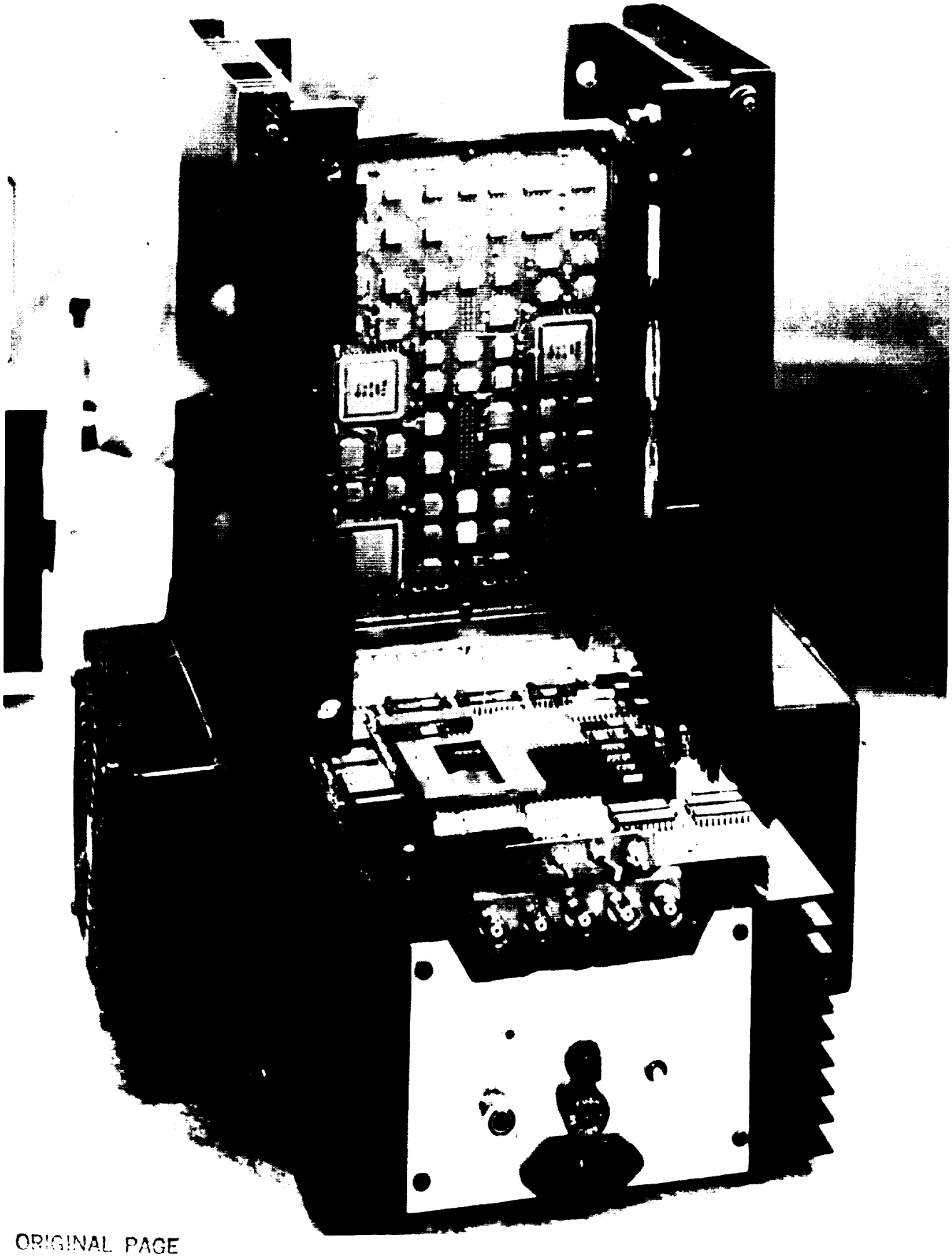
A VHSIC-compatible multiprocessing concept is being developed using and enhancing VHSIC MIL-STD-1750A components from DoD VHSIC contracts. The concept is being implemented as a distributed self-managing Graph Management Operating System (GMOS) which handles arbitrary application algorithms, provides node-select-able fault tolerance, and is written in Ada.

A contract (NAS1-18226, Task 1) was begun with SRI International in FY87 for: 1) the modification of the 4-processor VHSIC 1750A breadboard multiprocessor system; 2) development and simulation of performance of the GMOS; 3) development of a specific Ada algorithm for performance measurement and demonstration; and 4) measurement of GMOS multiprocessing efficiency and demonstration of system performance in the presence of fault scenarios. System performance will be demonstrated in the mid FY88. DAIS mix, Whetstone mix, and Kalman filter algorithms have been prepared and simulated on the ADAS system and are now being comparatively tested on pre-VHSIC processors and the TI VHSIC processor. LaRC is comparatively testing a VHSIC 1750A processor developed by the Army at Texas Instruments (TI) and evaluating a self-testing strategy for a 1750A processor developed on an SBIR effort.

LaRC is coordinating with the Air Force Space Technology Center (AFSTC) in the development of a MIL-STD-1750A Generic VHSIC Spaceborne Computer (GVSC) chip set by FY89. LaRC participated on the GVSC Phase II technical proposal evaluation in FY87 and contract reviews. Studies are underway to define adaptability of the GMOS to the GVSC. LaRC plans to exercise AFSTC contract options in FY89 to demonstrate GMOS features in a GVSC breadboard system. Approaches for a possible joint NASA-DoD effort to develop a full system spaceborne chip set are being explored to accelerate onboard system technology readiness.

TECHNICAL CONTACT: Harry F. Benz, LaRC (804) 865-3777

TI VHSIC 1750A PROCESSOR IN TEST STAND



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MAX: An Advanced General Purpose Computer For Space

The objectives of this task are to: 1) define a high speed, resource efficient, general purpose computing architecture and programming environment to serve the needs of future NASA space programs; and 2) introduce, exercise and evaluate new flight qualifiable device technology and components, including custom, semi-custom VLSI and VHSIC. The multifaceted approach included design and development of a breadboard system for parallel resource efficient architectures, and the hardware and software features necessary for flight programs; a programming paradigm to address the problems of concurrency, real-time operation, autonomy, and fault tolerance; a software development environment conducive to design, test, and maintenance large, real time programs; and the development of device qualification practices to facilitate the insertion of custom, semi-custom VLSI and VHSIC.

In phase I, begun in FY84, a prototype was developed using commercially available off-the-shelf single board computers forming a baseline for phase II begun in FY87 to build a flight qualifiable, fault tolerant, distributed computer and computing environment. Accomplishments in FY87 were many. The phase II version of the MAX Dataflow operating system, HYPHOS, was designed in detail using the PRISM software system design methodology which allows variable levels of fault tolerance transparently to the application programmer. A low level operating system kernel interface standard was developed to emulate the real-time scheduling constructs available in NASA's HAL/S high-level language. Global Bus Controller design was completed. Standard-cell implementations of the Meshwork Controller were fabricated using the MOSIS CMOS III process. These devices, including a receiver, transmitter and crossbar switch are compatible with the CCSDS Recommendations for Space Data System Standards. A DMA controller was designed to interface with Sandia's rad-hard SA3300 32-bit microprocessor and device family. National Semiconductor Corp. is currently considering plans to pick up JPL's design to include it into their NSC32000 product line. A VHSIC technology review was begun to evaluate ongoing efforts by the DoD to create high performance general purpose processors.

Future NASA space systems have computing requirements driven by the need for greater autonomy, expanded use of robotics and artificial intelligence, more complex sensors, much higher volumes of data, large structure control, and a variety of other performance enhancements. The majority of these needs may be fulfilled with flexible and capable general purpose computing which must also address the needs for complex software requirements to meet larger and more diverse requirements than ever before.

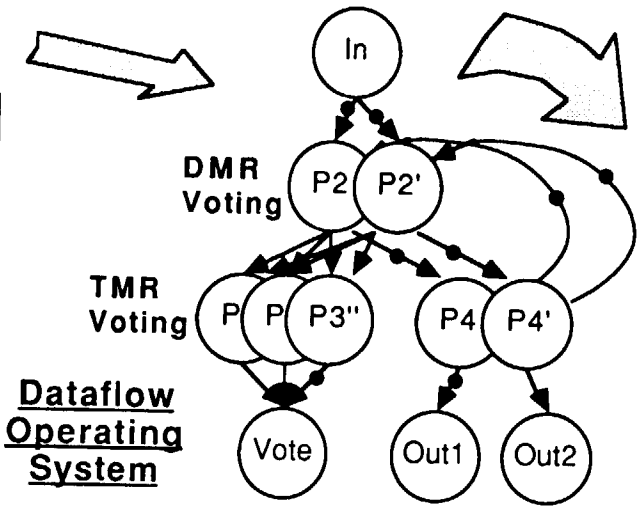
Plans for FY88 include final completion and demonstration of all features of the MAX phase II system architecture: the HYPHOS fault tolerant operating system; the Meshwork; DMAC; the Global Bus Controller; new Dataflow software development tools and documentation; and a five board multi-module MAX breadboard system. Additionally, a new technology survey will be undertaken which will lead to insertion of appropriate VHSIC technologies into the MAX program.

TECHNICAL CONTACT: Robert Rasmussen, JPL (818) 354-2861

JPL

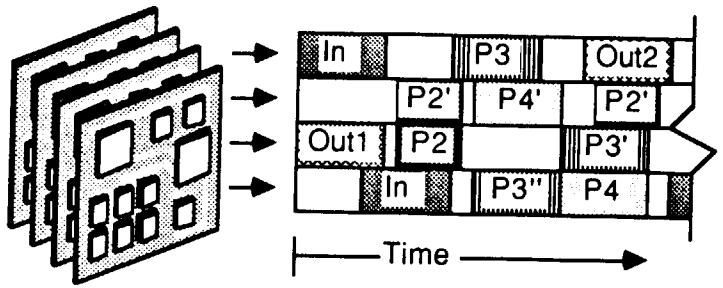
MAX
Flight Multi-Computer

Dataflow System Design

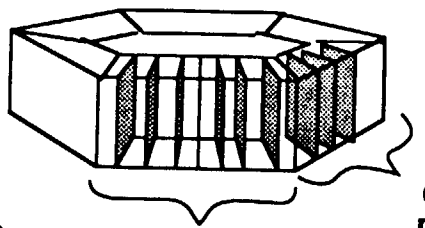


Dataflow Operating System

Dynamic Process to Processor Allocation



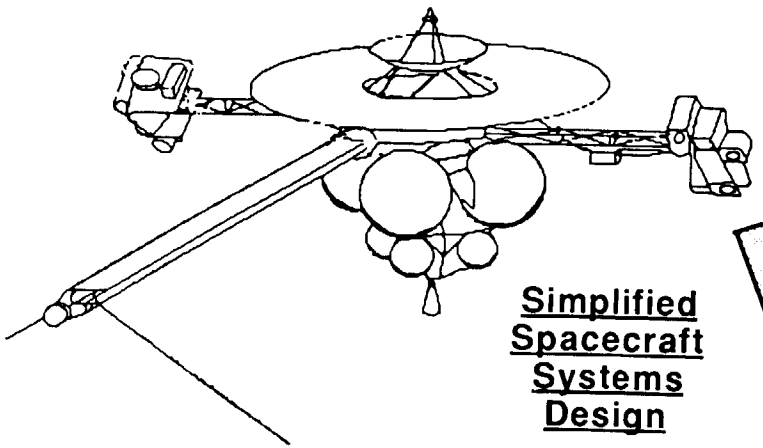
Shared Computational Resources



Electronics Bays

Command & Data System

Guidance Navigation & Control System



Simplified Spacecraft Systems Design

RMM 341 87

GaAs Adaptive Programmable Processor

The objectives of this program are to advance the state-of-the-art of onboard high data rate signal processing and storage applications through the use of advanced Gallium Arsenide (GaAs) integrated circuit technology and advanced computer architectures.

Processing for spacecraft sensors will need preprocessing onboard which requires high throughput efficiency, low power, and high reliability not achievable by current silicon components.

During 1987, an 8-bit slice general purpose processor, with controller, was fabricated using DOD's (Rockwell) GaAs pilot line. Initial probe testing of the wafers show a good yield of fully functional devices. These two devices, when integrated together, will implement a data compression algorithm that is designed to operate from a 200 MHz clock. In addition to the 8-bit slice activity, an analysis of NASA's sensor data processing functions has concluded that von Neumann computer architectures cannot meet the needs of the future high data rate instruments.

In 1988, a generalized non von Neumann architecture will be developed based on a register stack, imbedded ALU's and a controller which will enable bit slice and pipeline computer configurations. This architecture, when coupled with GaAs technology, will achieve operational speeds required by imaging preprocessors (e.g., $5x10^9$ op/sec).

TECHNICAL CONTACT: Warner H. Miller, GSFC (301) 286-8183

GA-AS ADAPTIVE PROGRAMMABLE PROCESSOR

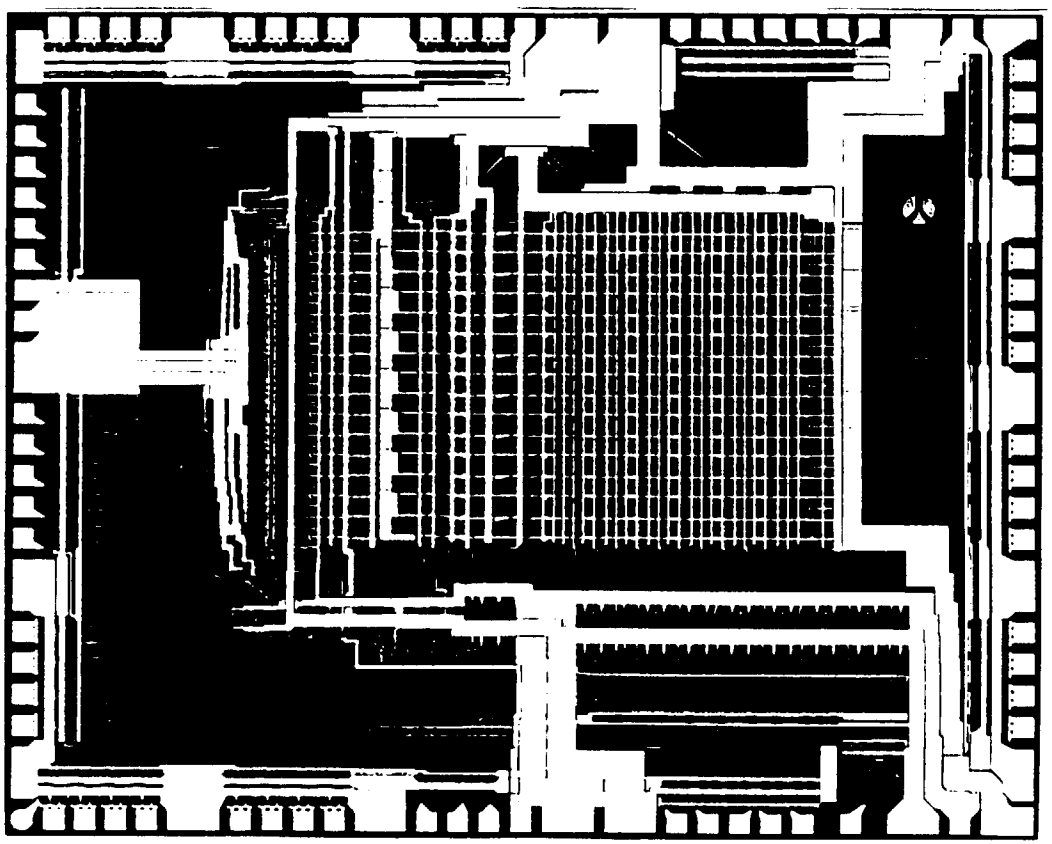
OBJECTIVE: HIGH THROUGHPUT SPACEBORNE PROCESSOR FOR HIGH RATE INSTRUMENTS

FY87 ACCOMPLISHMENTS:

- FABRICATED TWO WAFER LOTS ON DOD PILOT LINE
- WAFER PROBE TESTED 60% OF 8-BIT SLICES AND CONTROLLERS

FY88 PLAN:

- PACKAGE AND INTEGRATE 8-BIT SLICE AND CONTROLLER DEVICES
- DEMONSTRATE IMAGE DATA COMPRESSION
- TEST RADIOMETRIC CORRECTION BREADBOARD USING PIPELINE TECHNIQUES AND SILICON TECHNOLOGY
- INITIATE ARCHITECTURE DESIGN OF GENERALIZED PIPELINE PROCESSOR



GaAs 8-BIT SLICE GENERAL PROCESSOR

Fiber Optic Integrated Circuit Transceiver

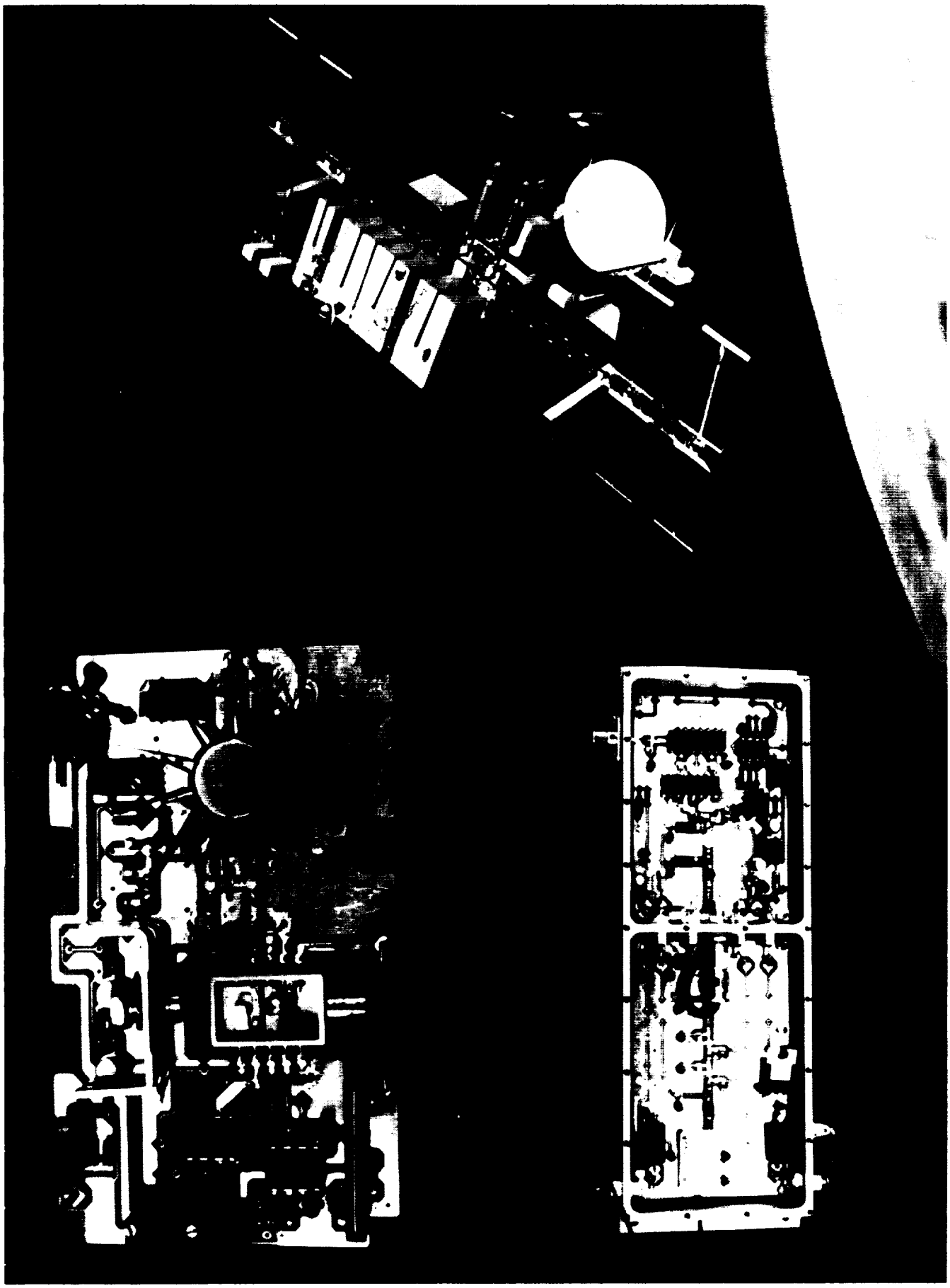
The objective of the Fiber Optic Integrated Circuit Transceiver development program is to develop/demonstrate Space Qualified Fiber Optic Integrated Circuit Transceivers to cover the data transfer range to 1000 Mbits/sec. The transceivers are being developed to coyer the following ranges: (1) 0 to 10 Mbits/sec; (2) 10 to 50 Mbits/sec; (3) 50 to 200 Mbits/sec; and (4) 200 to 1000 Mbits/ sec. Current transceivers are all of the hybrid design that use discrete parts plus some integrated circuits. A fully integrated circuit design will reduce the size, weight and power consumption of the transceiver and make the design more advantageous for use in the Space Station, EOS, Mars Rover, NASP and other advanced transportation systems. Utilization of GaAs parts will also enhance the speed capability and provide a higher degree of radiation hardness for missions requiring high data transfer rates and operation in a radiation environment.

This program will utilize and develop integrated circuits in both GaAs and Si for the integrated transceiver design through a joint program with the DOD/AF/Rome Air Development Center, Griffis, AFB, NY. A one year CAD design effort will utilize existing integrated circuits foundry devices from various manufacturers plus point out any needed device development work. Two bidders will be selected for a one year Phase 1. A 2-3 year development program will be awarded to the successful Phase II bidder.

The design and reports will be available for use on all of the various data systems users in the NASA community just as the MFOX (Multi-purpose Fiber Optic Transceiver) data is being made available through the Space Station Office and Code RC at NASA Headquarters. The design is also planned for use by the AF TAC as well as the Navy (NOSC) and the Army (CECOM).

TECHNICAL CONTACTS: Harry F. Benz/Herbert D. Hendricks, LaRC (804) 865-3777

FIBER OPTIC INTEGRATED CIRCUIT TRANSCEIVER



Spaceflight Optical Disk Recorder Development

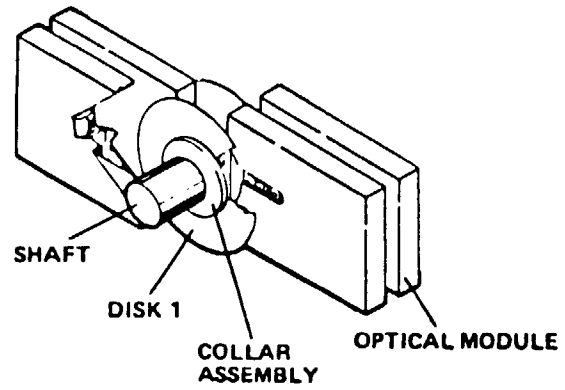
As part of the NASA Office of Aeronautics and Space Technology (OAST) Civil Space Technology Initiative (CSTI) Program, the Langley Research Center is developing a high rate/high capacity erasable optical disk recorder system for spaceborne applications in the '90's and beyond. The Spaceflight Optical Disk Recorder is based on a modular concept which is expandable to at least a tera (10^{12}) bit capacity, up to 1.8 Giga (1.8×10^{9}) bits/sec input/output data rate; and will provide fast random-access capability; representing capabilities which are critical to future space initiatives.

The volume of scientific data is anticipated to grow by a factor of 100 as we enter the era of Space Station and the Earth Observing Systems, with attendant large volumes of engineering data to support autonomous operations, robotic servicing and other operational requirements envisioned for future space initiatives. Data rates of the next generation of imaging sensors will exceed current data storage system capabilities.

Current tape devices require data-streaming to access critical data, a process which results in significant delays, takes the device off-line for recording, and can affect hardware lift-time. Fast random-access capability will be required to provide rapid access to the highest and most timely scientific and engineering data to enable near real-time interactive control of missions.

TECHNICAL CONTACT: Reginald M. Holloway, LaRC (804) 865-3541

EXPANDABLE OPTICAL DISK RECORDER CONCEPT

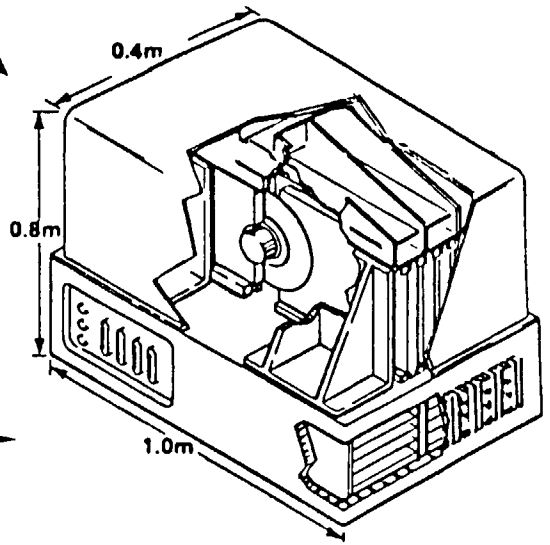


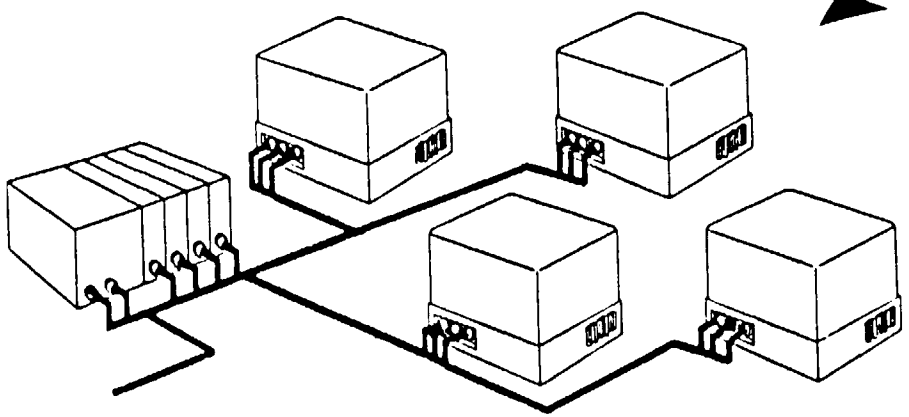
PERFORMANCE GOALS: DRIVE

Capacity	20 Gigabyte
Data Rate	300 MegaBits/S
Read Error Rate	<1 / TeraBit
Data Access Time	<0.1 Sec

FEATURES

- Erasable, Reusable Media
- Solid State Laser
- 2 Disks–4 Surfaces
- 4 Optical Heads
- 14-inch Disks
- 9-Diode Arrays
  - 8 Data Tracks
  - 1 Pilot Track





PERFORMANCE GOALS: SYSTEM

Capacity	1 TeraBits (6 Modules)
Data Rate	0.3–1.8 GigaBits/Sec

Concurrent I/O–Rate Change
Reconfigurable System

Flight SAR Processor

The primary objective of this task is to enable on-board processing of raw synthetic aperture radar (SAR) data into images for EOS-type spacecraft missions.

The technical approach is to first define a baseline on-board SAR processor architecture and then develop the enabling technology required for its flight implementation.

During FY86, this task defined a preliminary baseline design architecture for an on-board SAR processor applicable to EOS-type missions. This architecture reflects an innovative VLSI building-block implementation requiring no bulk memory. In FY87, a study to evaluate the application of inverse-sequence processing to the baseline architecture implementation was performed. This study resulted in 1) a new technology report to NASA, 2) a patent application, and 3) an updated baseline design architecture having significant power and mass reductions. In addition, a detailed tradeoff study of a time-domain versus frequency-domain implementation of the azimuth correlator function was performed in FY87 to adequately substantiate the selected baseline design architecture prior to follow-on development. Five technical papers, documenting the FY86 and FY87 results, were also written during FY87 for presentation at selected conferences.

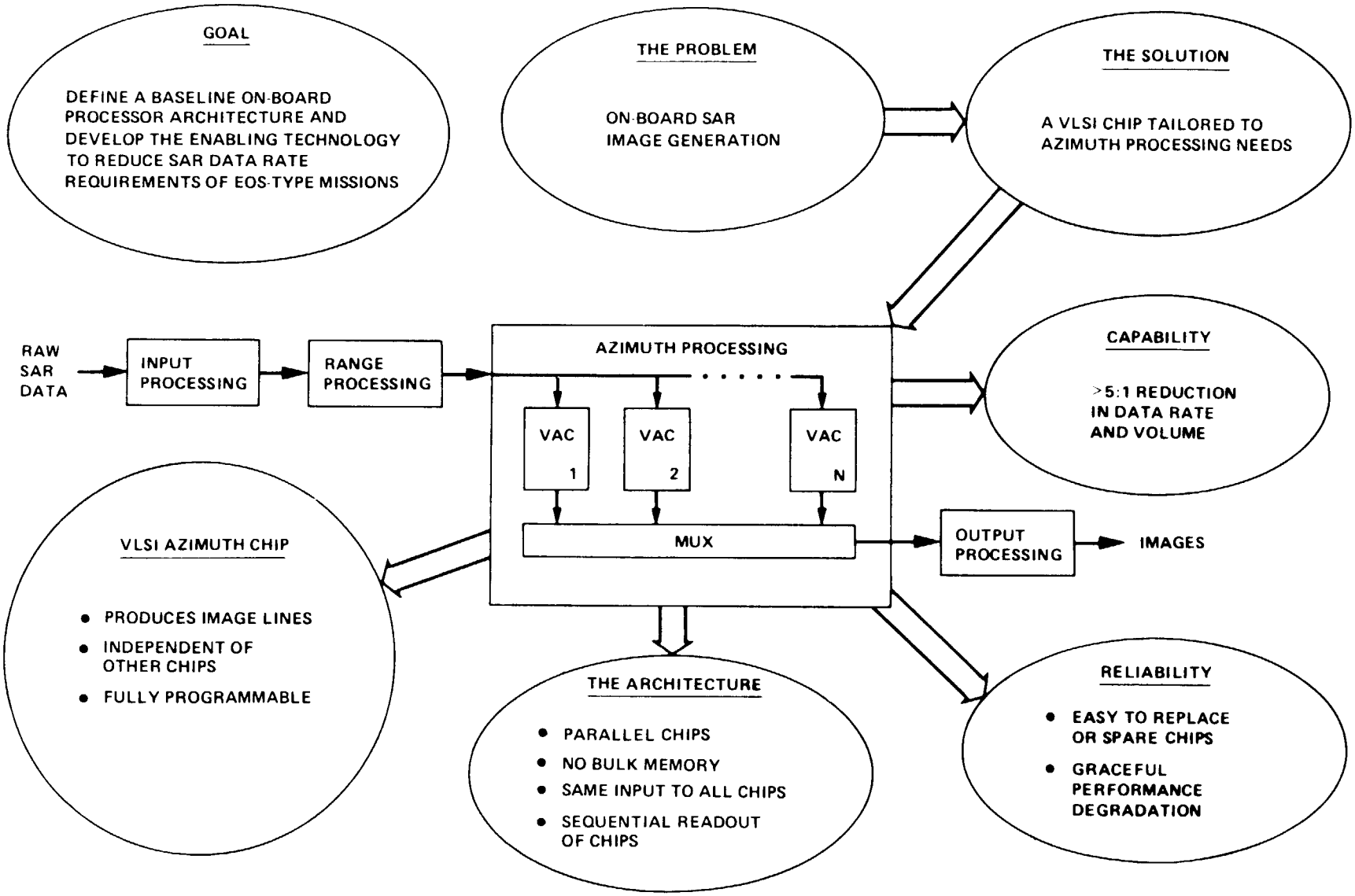
The SAR instrument for EOS-type missions produces very high peak data rates ($\geq$300 Mbps) that impose severe demands on the downlink and ground-processing facilities required to achieve efficient dissemination of information to users. On-board processing of raw SAR data into images is required in order to reduce these rates. Image generation also will allow a reduction of $\geq$5:1. It will also enable the use of image-based on-board compression strategies that can potentially reduce data rates by orders of magnitude. Until now, on-board generation of SAR imagery for EOS-type missions has been considered impractical based on power, mass, cost, and risk considerations.

During FY88, the preliminary design of a single azimuth processing channel will be performed. This design will be implemented with discrete components in a developmental testbed environment and used to support subsequent VLSI chip development. In addition, the functional requirements for and preliminary description of a VLSI building-block chip for implementing the azimuth correlator function will be accomplished in FY88. Follow-on work will include the development of a complete flight SAR processor breadboard using VLSI chip technology.

TECHNICAL CONTACT: David Nichols, JPL (818) 354-8912

FLIGHT SAR PROCESSOR TASK

JPL



Hierarchical Warp Stereo Algorithms on NASA's Massively Parallel Processor

A Hierarchical Warp Stereo analysis program has been implemented on the NASA Goddard Space Flight Center's Massively Parallel Processor (MPP). This program is capable of generating disparity values from which elevations can be calculated at all pixels of a 512 x 512 synthetic aperture radar (SAR) image within 53 seconds. The algorithm has been applied to stereo images produced by the Shuttle Imaging Radar (SIR-B) instrument.

TECHNICAL CONTACT: Dr. James P. Strong/Dr. H.K. Ramapriyan, GSFC (301) 286-9535

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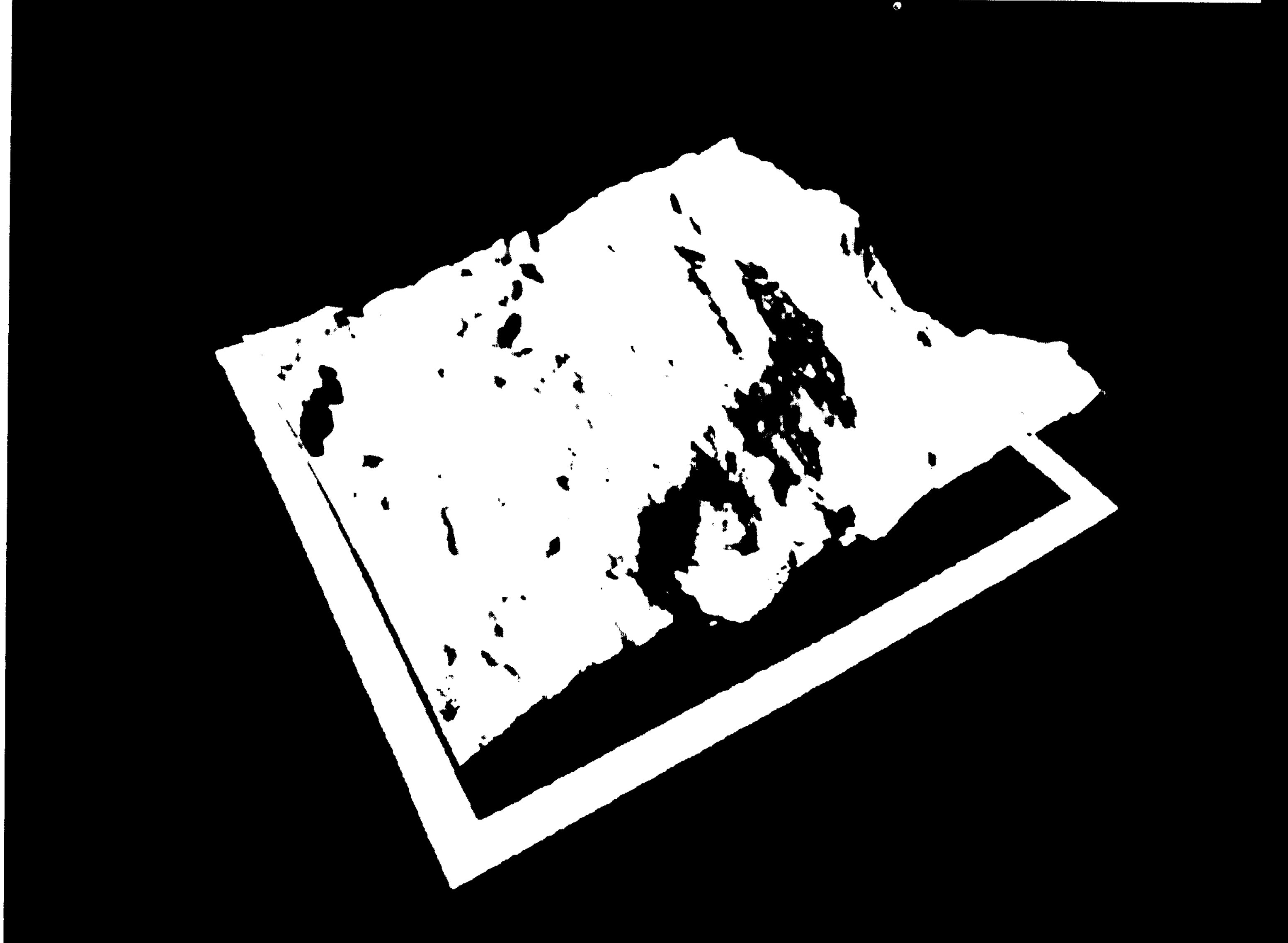
Perspective view of land topography at India's northeast border with Bangladesh computed from overlapping SAR images from the SIR-B instrument. Topography is based on disparity values computed by a Hierarchical Warp Stereo analysis program implemented on Goddard's MPP.



Riacs Sparse Distributed Memory (SDM)

Research in sparse, distributed memory is motivated by the desire to build robots that can be sent on remote missions where human presence would be desirable but is impractical due to the time it takes to reach destination or to the severity of conditions at the destination. The robot must learn by interacting with its environment. To do so, it must build an internal model of the world in which it operates, which is stored in the robot's long-term memory.

The sparse, distributed memory was developed as a mathematical model of human long-term memory, and its important properties are those needed for the robot memory. The theory of the memory was developed under assumptions of randomness that do not usually hold with natural data such as that arising from vision and language. Our present research is therefore aimed at extending the theory to dealing with correlated sets of data. Two sources of natural data are now under study: the reading of English and the recognition of hand-written characters. In the reading project the memory is trained to translate written text into phonetic transcription, and in the character-recognition project the memory is trained to identify characters. These "application studies" are carried out with memory simulators programmed for conventional computers. The studies are now in mid-course, with results expected by the end of 1987.

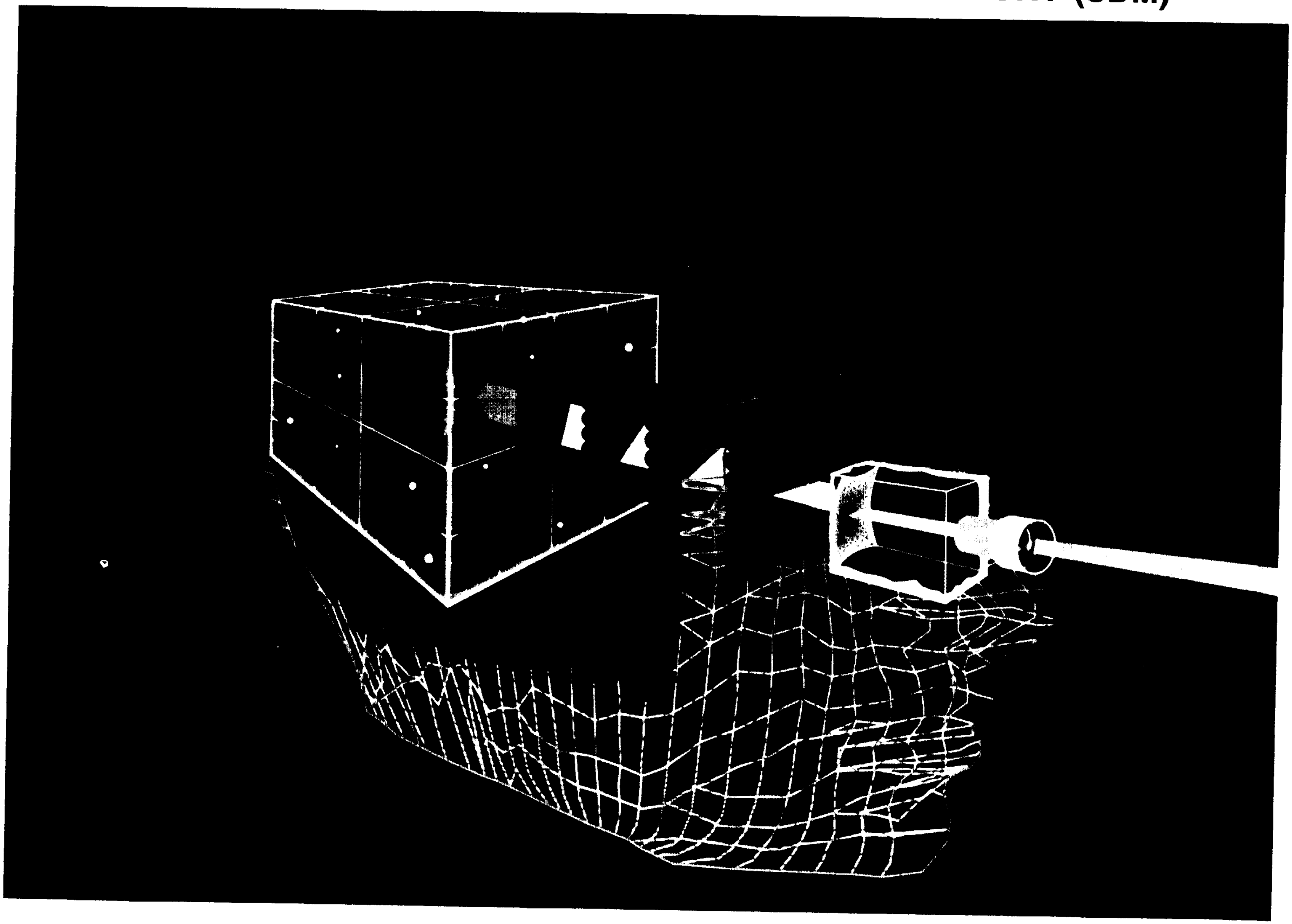
Besides being very slow, the simulators are very small in comparison to the memories required by practical applications. The technology for practical memories is being developed and should be ready in about ten years. The present simulators are large enough for the theoretical studies that must precede the construction of practical memories.

The third area of active research is into the overall organization of an autonomous system (a robot) that has a sparse, distributed memory for long-term memory. The first technical report on this is due at the end of the summer, while design specification of a digital prototype of a sparse, distributed memory is near completion at Stanford's Computer Systems Laboratory and is expected to be published jointly as a technical report by RIACS and Stanford before December. A digital prototype itself should be available by the end of 1987.

RIACS scientist Pentti Kanerva, inventor of the SDM, has completed a manuscript for a book about SDM, which will be published by MIT Press early in 1988, and a potential industrial affiliate has initiated discussions concerning a possible program which would place two of their scientists at RIACS, one working to implement SDM in a new, experimental technology and one working on a simulation of SDM on an existing parallel architecture.

TECHNICAL CONTACT: Michael R. Raugh, ARC (415) 694-5402

ROBOT INCORPORATING SPARSE DISTRIBUTED MEMORY (SDM)



Electronic Neural Networks With Modifiable Synapses

The overall objective of this program is to develop electronic neural networks for use as an autonomous logic module with self-learning abilities based on modifiable synapses and to identify the advanced applications of this technology to NASA missions.

The technical approach involves: a) the development of dense, nonvolatile arrays of modifiable synapses based on reversible, thin-film microswitch structures; b) interfacing the synaptic arrays with decision-making elements -- the neurons; c) a study of the advanced application potential of the networks by software simulation leading to the development of application-specific architectures; d) optimization of network architectures and their hierarchies (block-multiplexing) in hardware for specific applications; and e) integration of the block-multiplexed networks with other digital computers.

This program started in December of 1986. Initially (Dec'86-May'87), an extensive survey of materials and device structures for a reversible nonvolatile synapse has resulted in the selection of the following candidates: Doped Amorphous Silicon (A-SI) P-N-I-Structures, A-SI based thin film field effect transistors (TF-TFT), Chalcogenide glasses with reversible phase transitions, and tungsten oxide (WO_3) based electrochromic bistable memory devices. Synaptic test structures of these devices have been designed and their fabrication is in progress. For final selection of a synaptic material, its long-term novolatility, low energy switching, high density packing, and cyclability have been identified as critical. Furthermore, a dynamic study of neural network operation in software simulations and on the fast digital-analog hybrid simulator recently developed at JPL is underway.

Artificial neural networks attempt to mimic the intelligent information processing abilities of a human brain, accomplished through massive parallel architecture containing a number (N) of logic elements (Neurons) connected to each other with variable strengths through a large network of (N^2) interconnections (synapses). Electronic neural networks with nonvolatile, thin film modifiable synapses as autonomous self-learning, self-organizing, fault tolerant logic modules, interfaced with digital computers, will have a significant impact on the on-board operations in combinatorial optimization, AI and Robotics. These networks will serve as true hardware-based natural intelligence (NI) machines and as smart knowledge bases.

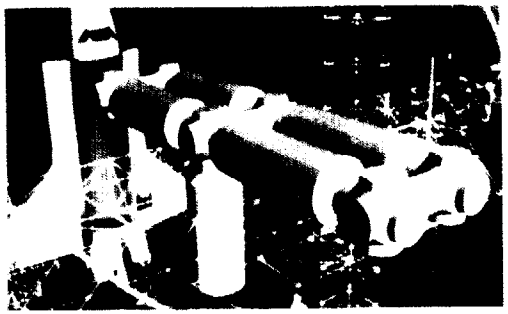
During FY'88, the design for the reversible synapses will be optimized, test structures and devices will be fabricated, and a study of advanced neural network applications will be initiated. Subsequent work will include the upward integration of these modifiable microswitches from synaptic arrays to neural network systems running concurrently with digital computers. Selection of applications for NASA's needs, and demonstration of neural network system performance will achieve the goal of this program.

TECHNICAL CONTACT: Anil Thakoor, JPL (818) 354-5557

ELECTRONIC NEURAL NETWORKS

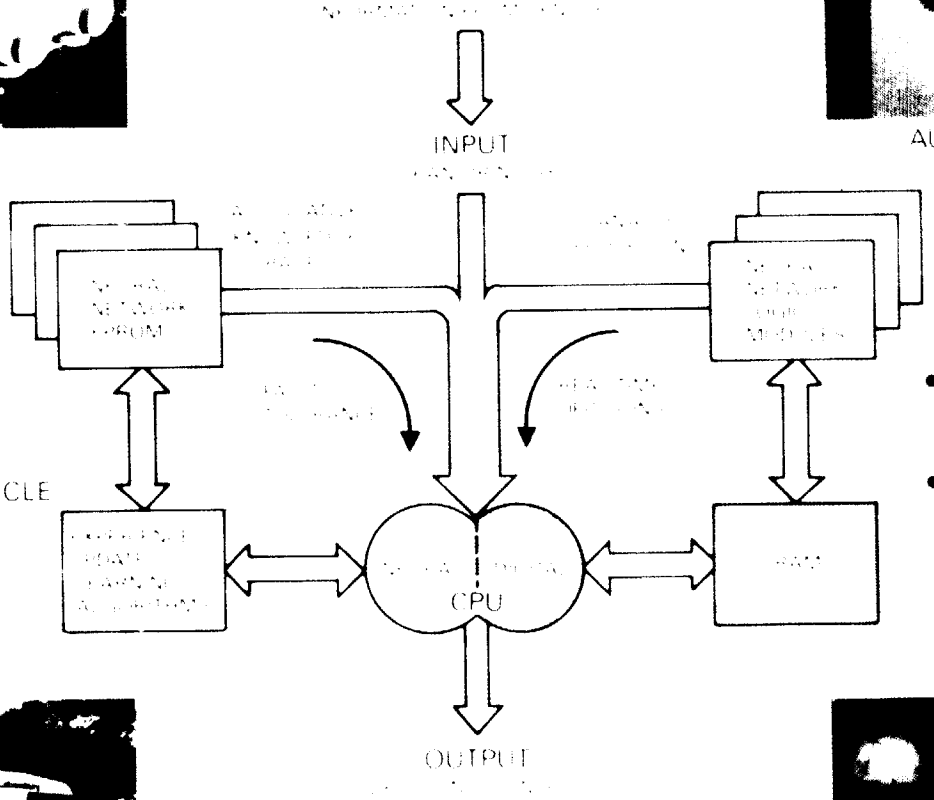
KNOWLEDGE BASES AND LOGIC MODULES

JPL



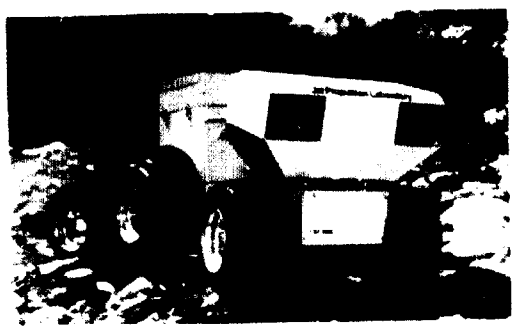
SPACE STATION

AUTOMATION AND ROBOTIC CONTROL



- SCIENCE INSTRUMENT MODULE CONTROL
- LOCOMOTION AND VEHICLE CONTROL

- RESOURCES ALLOCATION ON SPACECRAFT
- MISSION PLANNING AND SCHEDULING



AUTONOMOUS ROVER AND LANDER

- COMMAND AND DATA HANDLING
- PATTERN RECOGNITION

TERRESTRIAL APPLICATIONS

Human Factors - Aeronautics

The objectives of the aeronautics human factors research and technology program are to provide the technology base and capability to design effective crew-cockpit systems and to advance solutions to human problems affecting air transport and rotorcraft effectiveness and safety. Advanced automation technologies, new information display capabilities under computer control, and concern for the effects of human error in flight operations are elements which drive the directions of the program. Thus, the program has four thrusts: (1) flight management; (2) human engineering methods; (3) rotorcraft; and (4) subsonic transports.

Flight management research is aimed at development and evaluation of methods and techniques that allow the crew to deal with various problems in the flight environment. An expert system called Faultfinder was developed and is being evaluated to allow early detection of engine failures and to recommend to the crew alternatives in power management for safe operations. Studies were completed which established the minimum amount of information to be displayed to the pilot in an advanced tactical aircraft. Additional research was performed on an advanced, three-dimensional display method which shows a path in the sky to be followed for different flight regimes.

Human engineering research has had a long term objective to implement state-of-the-art psychophysiological response measurement methods as an aid in crew workload assessment. Several studies were completed which resulted in an improvement in sensitivity whereby heart rate variability is measured during various types of flight operations. Workload associated with low demands on the pilot result in boredom. This mental state was measured and evaluated by a new psychophysiological model.

Rotorcraft research focused on the different kinds of human visual requirements for effective nap-of-earth (NOE) operations and the subsequent design considerations for helicopter operations and displays. Studies were performed on workload and operational tasks of pilots involved in unusual rotorcraft operations, such as police surveillance and medical evacuations. A data collection program was initiated to gain data in an attempt to understand and deal with the high number of incidents and accidents in these types of operations.

Subsonic transport research, including commuter and general aviation, is intended to develop and evaluate technologies that the crew can use to detect and successfully avoid/escape wind shear hazards. Data on wind shear statistics, structure and severity were collected and used to develop and evaluate flight guidance techniques for recovery and escape. Concepts for the display of wind shear information and route of recovery and escape were identified as well and simulation data was obtained to further guide display development.

Extensive plans have been prepared and coordinated between Ames Research Center and Langley Research Center for a new initiative, called Aviation Safety/ Automation, which will start in FY89. Its objective is to focus results of the existing baseline research in order to improve the national airspace transportation system capacity and safety and to demonstrate and transfer

effective technology to the national aviation community. This technology will allow optimal integration of humans and automated systems, provide human-centered automation in air traffic control and flight systems, and support and improve human capabilities through fully compatible cooperative air-ground systems.

PROGRAM MANAGER: Dr. James P. Jenkins
NASA/OAST/RC
Washington, DC 20546
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Traffic Alert and Collision-Avoidance System (TCAS)

The Traffic Alert and Collision-Avoidance System (TCAS) has been under development by the FAA and industry for a number of years. Now that the system is nearing the point of deployment in routine operations, it has become necessary to evaluate the use of the system by line pilots in realistic operational situations. Several airlines are conducting limited implementation testing of the TCAS-II system, which provides vertical guidance only, during selected flight operations. NASA, the FAA, and industry are conducting full-mission simulations of TCAS at Ames, where a comprehensive set of conflict scenarios can be investigated in a safe, controlled, but realistic, research setting.

Initial research results on TCAS have demonstrated a significant potential for increased safety in flight by reducing the number of unsafe separation situations. Pilots were able to respond more quickly than the TCAS design specification of five seconds. On the other hand, excessive altitude deviations were observed which could prove problematic under operational conditions.

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Charles E. Billings, ARC (415) 694-5718

ARTIST'S CONCEPTION OF TCAS ENCOUNTERS

Aviation Safety Reporting System (ASRS)

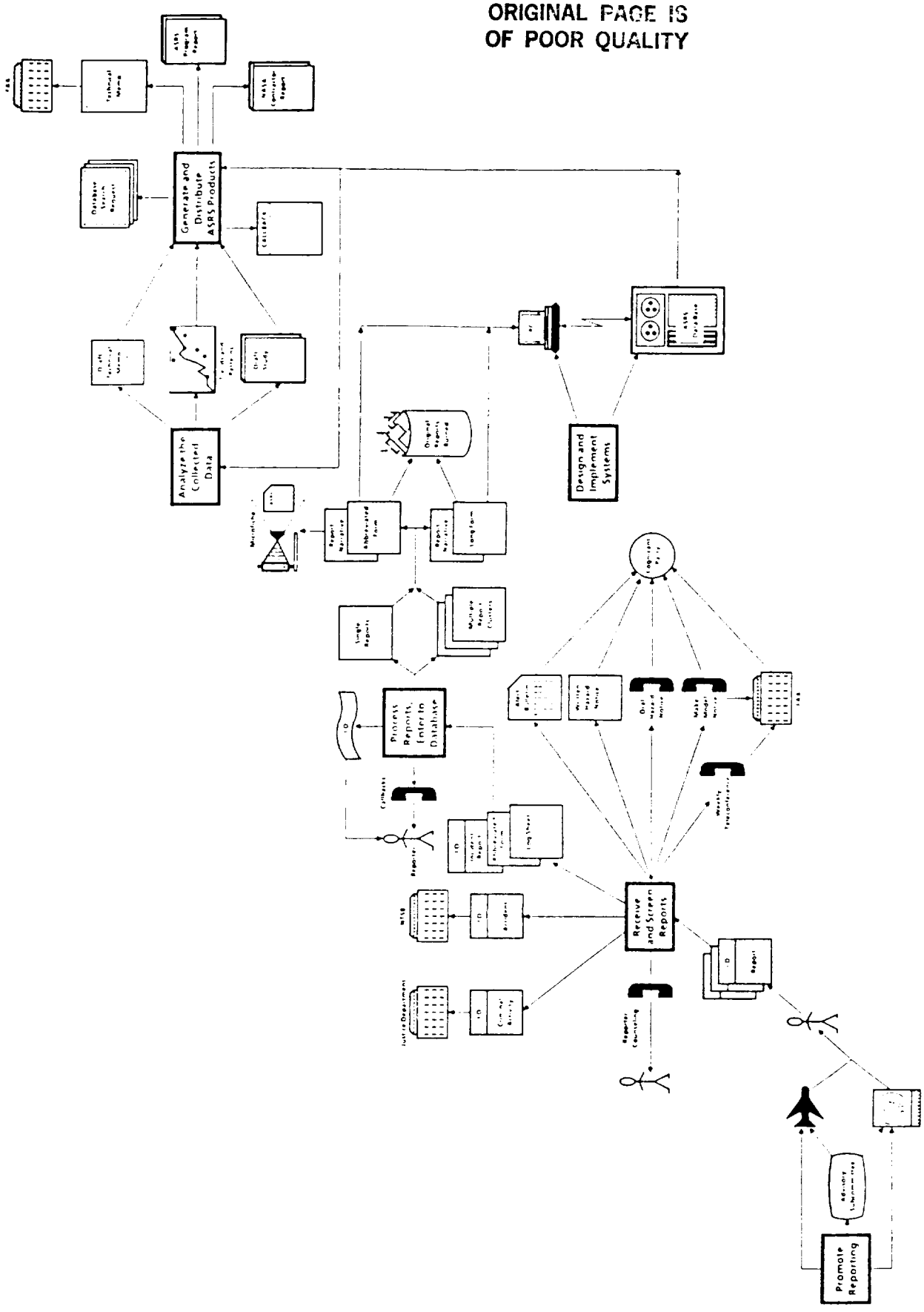
The ASRS has processed nearly 70,000 reports since it was established at Ames Research Center at the request of the FAA in 1976. During that time it has issued over 1,000 research reports and alert bulletins to further improve safety in the airways. The ASRS database has become a major resource to guide NASA human factors research, and it is also heavily used by the FAA, NTSB, DOD and other government, industry, and safety organizations. The incident reporting system has proven so effective in promoting safety and in stimulating safety awareness that it has been used as a model for similar programs in other countries. It has recently been used as a model for the NASA Safety Reporting System (NSRS), approved by the Administrator to support the collection of safety-related information for the space program.

Major on-going ASRS research activities include the compilation and analysis of incidents involving air carrier operations impacted by Minimum Equipment List (MEL) issues; operational errors in the Air Traffic Control (ATC) system; pilot deviations and near mid-air collisions in the National Airspace System (NAS). In addition, the ASRS database is currently supporting aviation human factors research on Terminal Control Area boundary conflicts, emergency cockpit management issues, safety issues associated with "hub" operations, VFR navigation in complex airspace, and operational issues associated with competitiveness or "economics in the cockpit". Recent heightened interest in human error and human factors in aviation has underscored the value of the ASRS database and related research activities.

TECHNICAL CONTACT: William Reynard, ARC (415) 694-6464

ORIGINAL PAGE IS
OF POOR QUALITY

ASRS's MAJOR ACTIVITIES



Information Transfer in the National Airspace System (NAS)

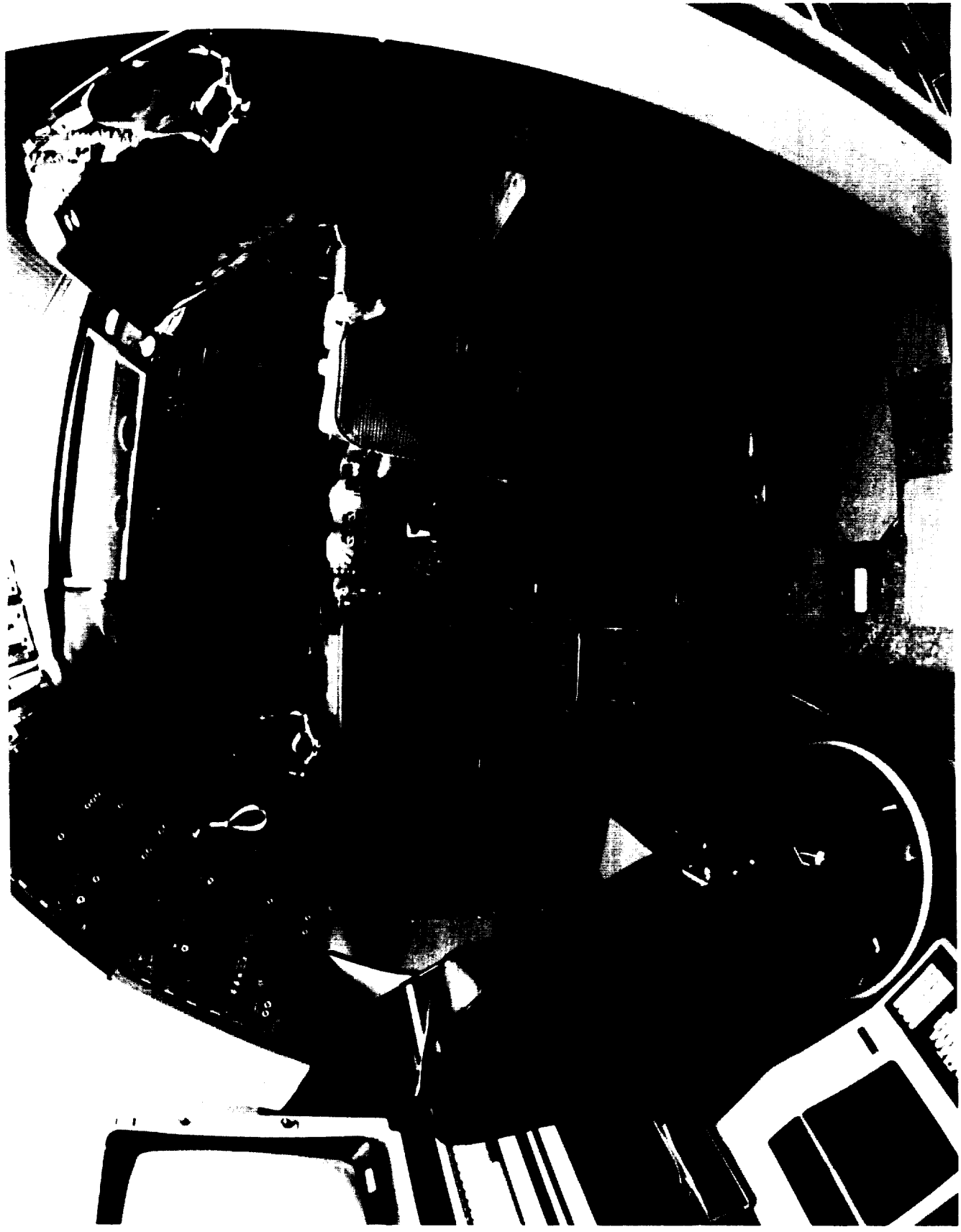
Information transfer problems have long been identified as playing a significant role in operational error. As the National Airspace System (NAS) becomes more complex and sources of information in the cockpit proliferate, information transfer problems can be expected to increase. The problem of determining information management requirements for modern cockpits is a pressing one if improvements in efficiency and safety are to be realized in the coming decade. Automated systems such as Datalink could provide new capabilities in information management provided that they are properly designed to take account of the characteristics of human information processing.

During FY87 a study of information-based incidents in the ASRS database was conducted to define the limitations of current information management systems and to identify contributing and causal factors in information transfer errors. A random sample of 610 reports was analyzed. Slightly over half of the errors resulted in aircraft position deviations, 16% in airspace or runway incursions, and 9% in conflict with other aircraft. Approximately half of the incidents were due to crew misunderstanding or distraction, with the remainder attributable to frequency congestion or other factors. Three-fourths of the incidents occurred during VMC operations.

The conclusions drawn from this project were that the majority of information transfer problems are associated with aircrew comprehension and memory limitations; that there is a need for more detailed information about incidents, and especially for more controller reports; and that technology enhancements such as Datalink could markedly reduce human error.

TECHNICAL CONTACT: Alfred Lee, ARC (415) 694-6908

CONVENTIONAL COCKPIT



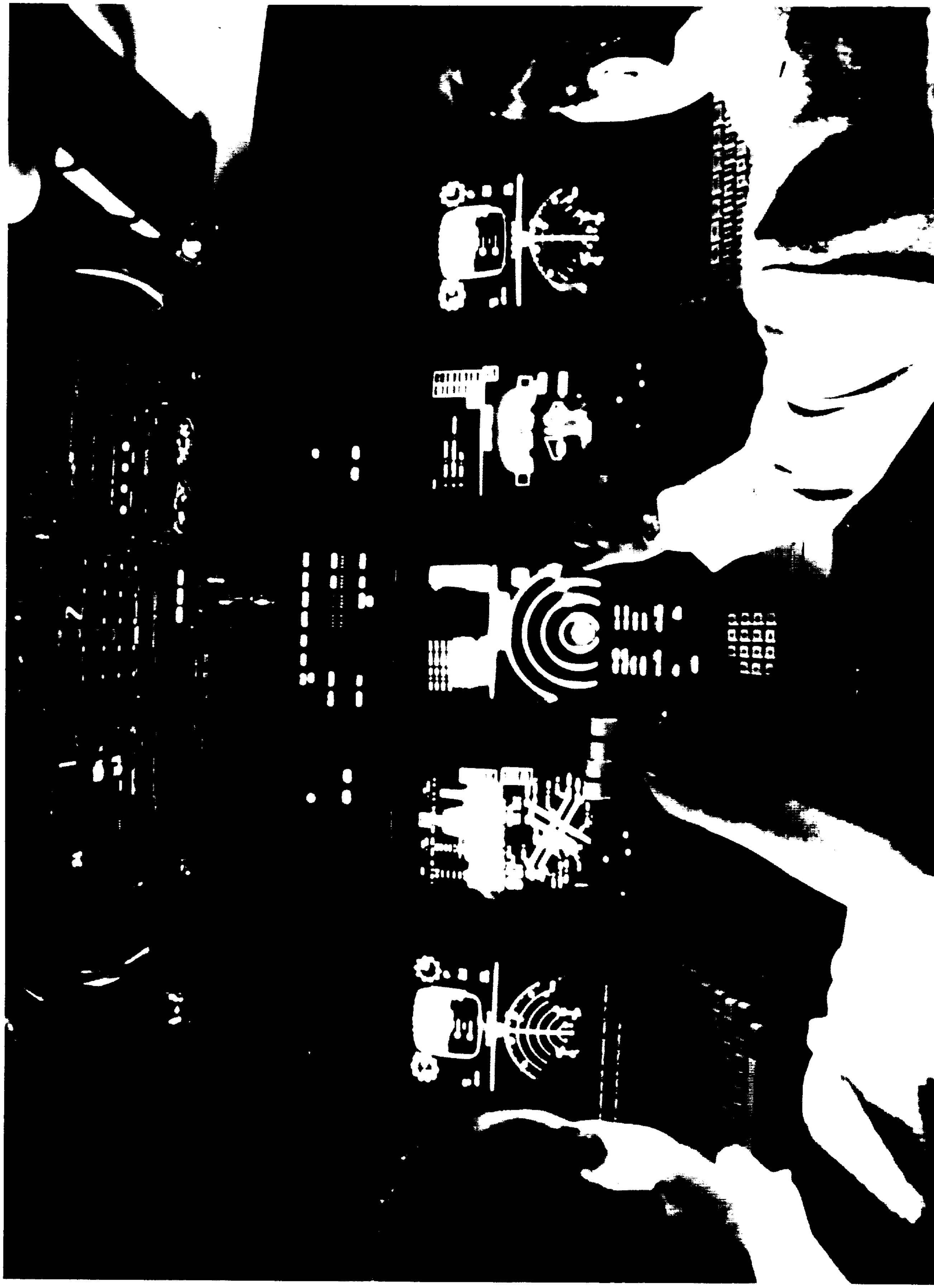
Field Studies of Advanced Technology in Transport Aircraft

The goal of this field study is to determine by direct contact with line pilots, instructors, and supervisors, the problems being encountered in operations with advanced technology aircraft. Many problems and benefits of new technology appear only after extensive pilot experience in actual line operations. Field studies provide a systematic way to document and learn from the experiences of aircraft operators and pilots.

Two airlines are participating, and over 200 pilots have volunteered for the study. The principal investigator has attended ground school and has made a large number of observation flights. The first phase of the study is complete. Initial results show that pilots are generally very positive about the aircraft and its innovative automated features. They do, however, have some reservations about specific characteristics of certain automated subsystems. Pilots feel that automation reduces workload in routine operations but increases it if the Flight Management System must be reprogrammed. They are concerned that there is too much head-down time and that the ATC system cannot take full advantage of the new capabilities of the aircraft. They feel that skill degradation is a real concern, and they take active measures to avoid it. Finally, they feel that crew coordination issues are especially important in automated aircraft.

TECHNICAL CONTACTS: Everett A Palmer, ARC (415) 694-6073
Susan Norman, ARC (415) 694-5717

ADVANCED TRANSPORT COCKPIT



Individual Crew Factors

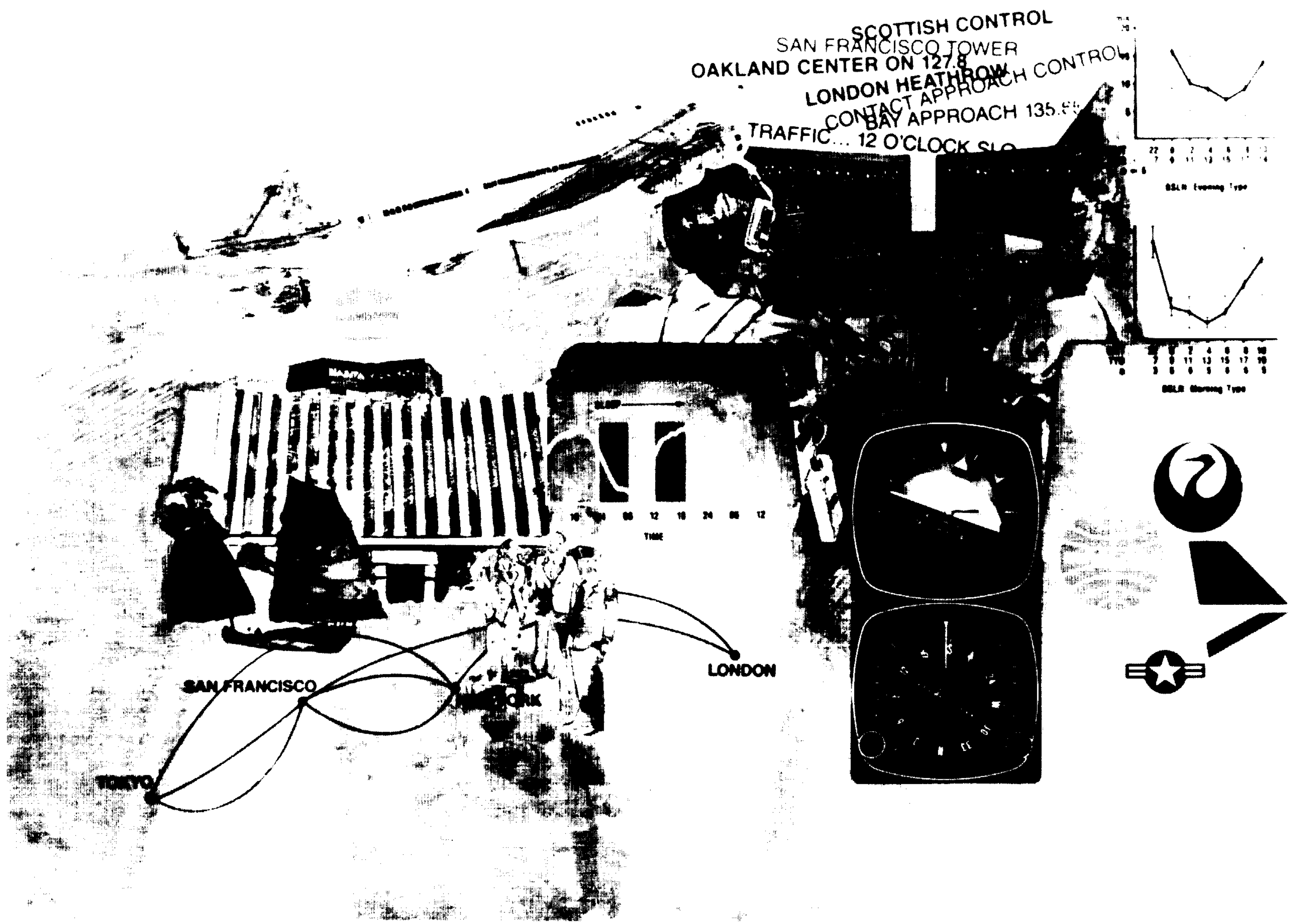
More than five years ago, Congress mandated research by NASA on the impact on flight safety of fatigue and jet lag among crews. From the outset, a high-priority goal of this program has been to discover and validate effective countermeasures to operational performance decrements.

Flight crew fatigue in short haul operations and its impact on performance were assessed in a comprehensive set of early studies. Although objectively measured pilot fatigue increased over the course of multi-day trips, performance of crews at the end of such trips was sometimes better than that of fresh crews who had not flown together recently. Subsequent analysis showed that the increased crew coordination associated with experience provided a strong countermeasure to the negative effects of fatigue.

Jet lag and fatigue effects for long haul operations were assessed in a more recent set of ambitious studies requiring extensive international cooperation. In these studies, jet lag effects have been measured more thoroughly than in any other operational study ever conducted. One entire issue of the journal Aerospace Medicine and Environmental Physiology was devoted to the research during FY87; Ames scientists won awards for the best articles published in this journal for the entire year. NASA has recently been asked to assist in the development of certification criteria for advanced long haul aircraft, and data from these studies will play a critically important role in this process.

TECHNICAL CONTACT: Curtis Graeber, ARC (415) 694-5792

FATIGUE AND CIRCADIAN FACTORS IN FLIGHT CREW PERFORMANCE



Procedure Error Detection and Error Tolerant Systems

Human error accounts for more than three-quarters of all aircraft accidents. New forms of automation, if properly designed, evaluated, and integrated with other cockpit systems, could significantly reduce the impact of human error during aviation operations. One requirement for an error-tolerant cockpit is the ability to understand crew actions and automatically detect pilot errors. This research effort seeks to develop a software program using a script-based model of crew behavior that can track flight-crew activity and detect pilot errors.

The script knowledge-base for a Boeing 727 flight was completed, the activity tracker and error detector were implemented, and data from four simulated 727 flights have been analyzed during FY87. Current work is focused on the completion of the initial 727 data analysis. The script-based program will be extended to predict the consequences of detected errors and experiments will be conducted to evaluate different approaches to activity tracking. Finally, the program will be implemented as a "smart checklist" and evaluated in the Advanced Cockpit Flight Simulator at Ames.

In a related effort, a study was conducted to determine the feasibility of applying artificial intelligence (AI) to flight path control and pilot activity tracking. Application of AI to flight path control was found to be feasible in transport operations. A review of Emergency Medical Service (EMS) accident data indicated that a ground/obstacle proximity warning system has the potential for preventing a large number of fatal weather-related EMS accidents. A probabilistic framework for pilot activity tracking and goal inferencing has been developed, and a prototype system is nearing completion.

TECHNICAL CONTACT: Everett A. Palmer, ARC (415) 694-6073

BOEING 727 COCKPIT PROCEDURES

Developed Prototype Onboard Fault Monitoring and Diagnosis Expert System

Current onboard caution and warning systems alert the flight crew to parameters which are outside the normal operating range. When a failure occurs, many parameters may go out of range simultaneously. Such a situation requires the flight crew to assimilate a large amount of information and provide a diagnosis, often with time constraints. Expert systems technology has demonstrated success in a number of application areas, but mainly in static environments. The objective of this research was to apply existing technology as appropriate, develop new concepts as necessary, and evaluate the resulting concepts for aiding transport flight crews in performing onboard fault monitoring and diagnosis.

Four different sources provided information for onboard fault monitoring and diagnosis requirements. First, pilots were interviewed to determine their information requirements and to identify how they perform fault diagnosis. Second, pilot handbooks were examined to assess the emergency procedures that flight crews are trained to use. Third, actual accident and incident cases were examined to determine the failure situations that pilots have difficulty diagnosing. Fourth, psychology literature provided information on how humans perform fault diagnosis and where they make mistakes.

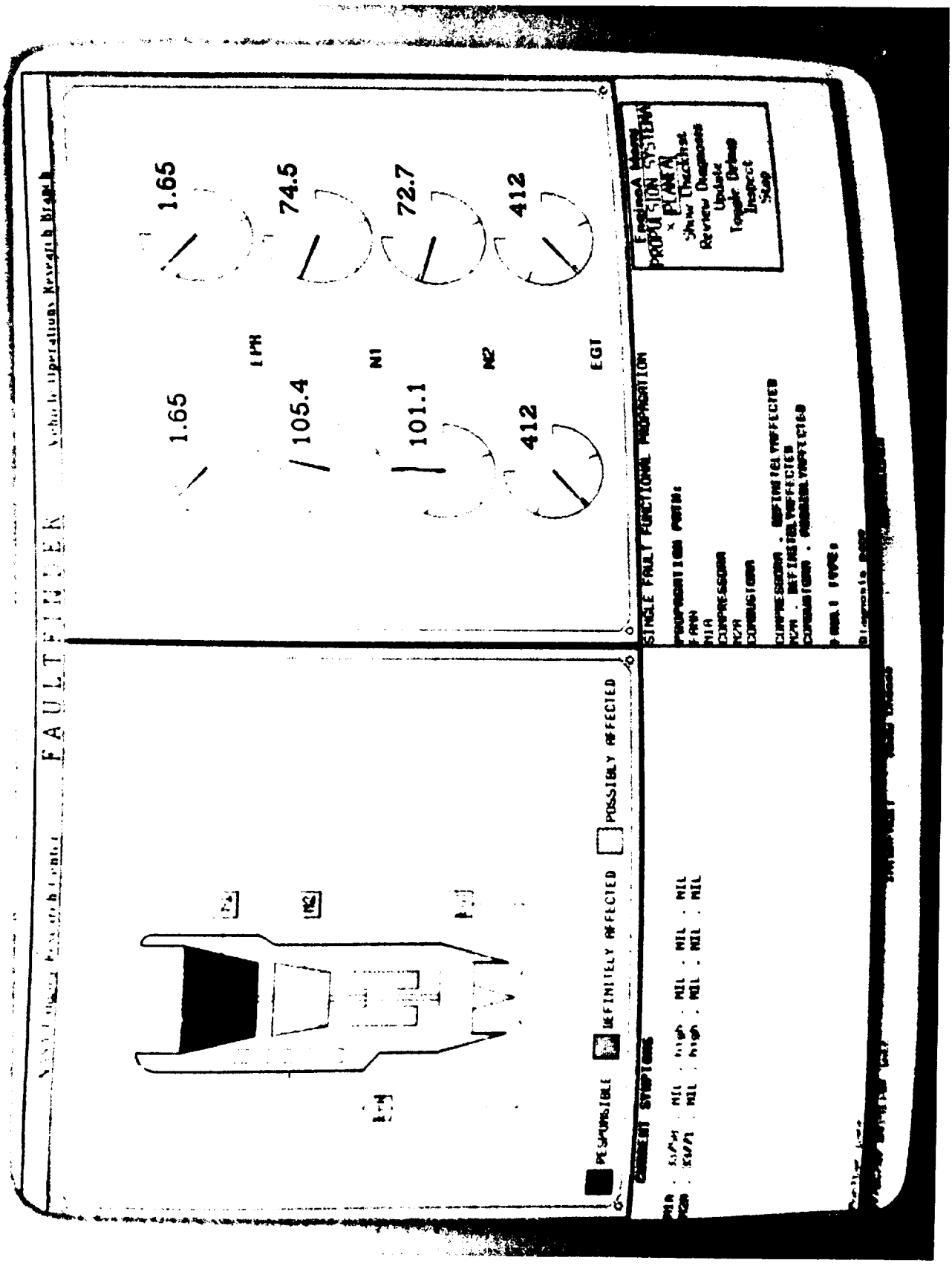
Based on the analysis from the four information sources, a conceptual architecture for an onboard fault monitoring and diagnosis expert system was developed and implemented in a computer program called "Faultfinder." The approach implemented in "Faultfinder" separates the monitoring process from the diagnosis, as shown in the accompanying figure. "Faultfinder" is unique in that it utilizes qualitative, causal, and temporal reasoning to perform diagnosis of known faults as well as unanticipated failures. "Faultfinder" is currently implemented for diagnosis of an aircraft propulsion and hydraulic subsystem.

"Faultfinder" is designed to diagnose failures which in the past resulted in serious aircraft accidents (e.g., the DC-10 engine separation). The concepts demonstrated in "Faultfinder" provide potential for improved failure detection time and increased crew situational awareness when failures occur, which may result in reduced loss of life and property.

Studies evaluating these concepts in piloted simulation tests are planned in order to quantify the benefits and to examine crew interface issues.

TECHNICAL CONTACT: Kathy H. Abbott, LaRC (804) 865-3621

FAULTFINDER DISPLAY OUTPUT

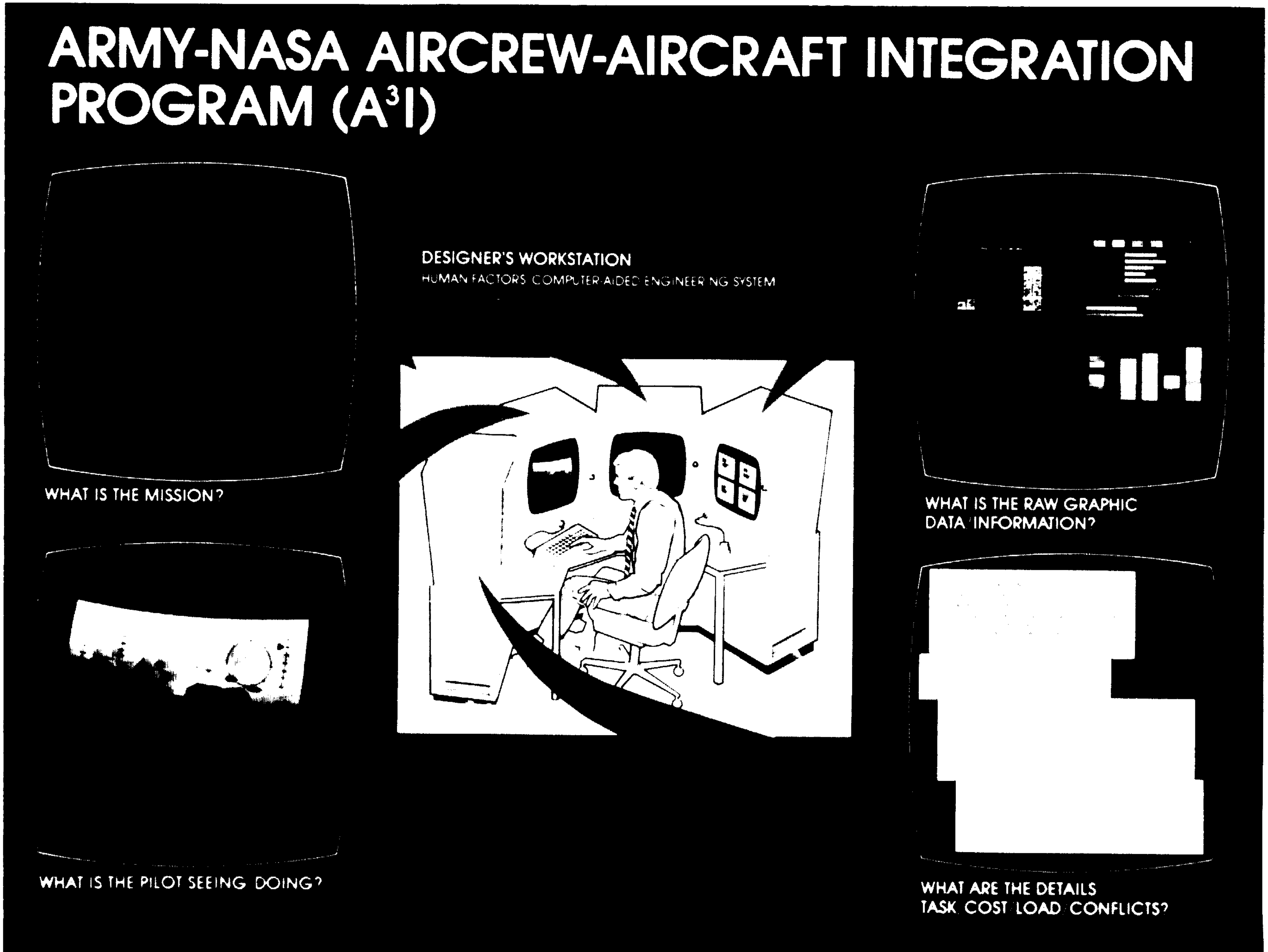


Army-NASA Aircrew/Aircraft Integration Program (A^3I)

The A^3I program is an Army-NASA exploratory development program with the purpose of developing a predictive design and human engineering methodology for helicopter cockpit systems. The program seeks to integrate human factors engineering, mission requirements, and training system implications with other vehicle and system design disciplines at an early stage in the development process. A prototype Human Factors/Computer Aided Engineering (HF/CAE) workstation suite is being designed and implemented. This interactive environment will include computational tools and expert systems for the analysis and estimation of the impact of cockpit design specifications on actual mission performance. Special emphasis has been given to the estimation of system performance from the standpoint of the human component of the system. This perspective is motivated by the high costs of redesign and retrofit to suboptimal systems, the ever-increasing costs of simulator-based training systems, potential life-threatening situations, and loss of mission effectiveness due to poor human-machine design. The long-range goal is to extend the methodology developed in this program to a general paradigm for the planning and execution of a wide variety of complex engineering tasks in human-machine systems.

During FY87 several new computer-aided design capabilities were developed. These include three-dimensional graphic rapid-prototyping and animation systems for flight displays and cockpit layout; a system for simulating out-the-window views from DMA databases; and a knowledge representation framework for mission and flight task representation. Development of a visual programming language for aircraft flight and system simulation has been initiated, and computer-aided design and training advisory systems are being tested and refined.

TECHNICAL CONTACT: James Hartzell, ARC (415) 694-5743



Visual Motion Sensing and Ego-Motion Perception

It has been established that visual motion, sometimes known as optic flow, is an important cue for pilots of both rotorcraft and fixed-wing aircraft. Computational models of human motion sensing are being developed and tested in order to understand pilots' processing of visual motion information and to extend the motion sensing capabilities of autonomous vision and guidance systems. Two- and three-dimensional motion flow estimation algorithms have been transferred to an array processor to increase computational speed. Experiments are being conducted to validate the model underlying these algorithms, and the assumptions of the model are being related to physiological motion-sensing mechanisms. Laboratory work is being extended to demonstrate aircraft state estimation from natural image sequences, with possible applications to visually guided flight and to autonomous guidance systems.

Initial algorithms were developed for estimating aircraft and world states from optical flow. By using a specific pattern of connections among directionally selective motion sensors, it is possible to construct a system for extracting 3-D ego-motion parameters (heading, rotation, and environmental layout) from the 2-D retinal velocity field generated by motion through a rigid environment. A 3-D motion filter can be constructed for a particular heading direction by connecting a set of 2-D motion sensors which are directed radially outward from the filter position. Activity in the sensors is summed. When an array of such 3-D filters is used, forward translation produces a peak of activity in the filter which coincides with the direction of the heading. Activity generated by pitch and yaw motion of the camera is subtracted out, and roll is detected by a separate pattern of sensor connections. Preliminary testing shows this system to be robust over a wide range of conditions. The system has several advantages over traditional approaches: there is no iterative searching for a solution; a hardware version would be a very fast real-time system with a solution generated every two frames; and the architecture is biologically plausible.

TECHNICAL CONTACT: John Perrone, ARC (415) 694-5150

PERCEPTION AND COGNITION RESEARCH

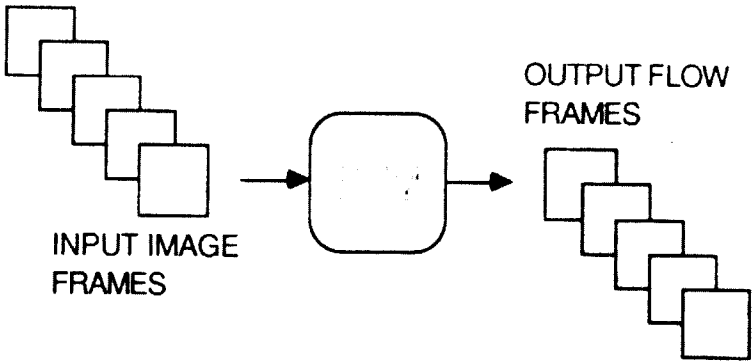
VISUAL MOTION SENSING

OBJECTIVE

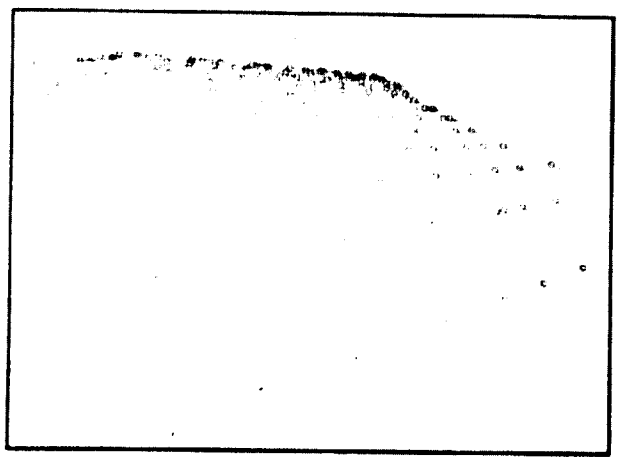
- COMPUTATIONAL MODELS OF HUMAN MOTION SENSING
- MOTION SENSING FOR AUTONOMOUS VISION

APPROACH

- VALIDATE MODEL AGAINTS HUMAN DATA
- IMPLEMENT FLOW-THROUGH CODE
- DEVELOP 2D-3D ALGORITHMS
- MODEL OF EGO-MOTION PERCEPTION
- DEMONSTRATE AUTONOMOUS GUIDANCE



DESIGN OF FLOW-THROUGH MODEL



EGO-MOTION FROM 2D FLOW FIELDS

AUTONOMOUS GUIDANCE

Rotorcraft Pilot Interface

Unusual interface systems for rotorcraft can create significant cognitive and perceptual difficulties for pilots. For example, when pilots track targets using helmet-mounted displays, the velocity flow field is distorted whenever the sensor is slewed during forward translation. This decreases the pilot's ability to determine the correct heading direction. Pilots also encounter serious and persistent problems in using night vision systems, due to low resolution, reduced field of view, monocular display format, and offset sensor location. Current technology not only creates perceptual problems for the pilot, but also requires very difficult shifts of attention between monocularly displayed sensor images and direct visual information inside and outside the cockpit.

During FY87, experiments and analyses evaluated the use of augmented displays to enhance the pilot's awareness of spatial orientation. Experiments using an advanced helicopter simulator and Honeywell IHADSS revealed that pilots have difficulty executing simultaneous tracking and control tasks. A joint program was established with the Technion Israel Institute of Technology and the Israeli Air Force to evaluate the effectiveness of computer-based training programs in the acquisition and performance of general flight-management skills. A task and skill analysis has been completed, and a specialized ground-based training system has been designed and implemented. Starting in October, this program will be evaluated with a group of incoming pilot-trainees. Their total training times, flight school retention statistics, and flying performance will be compared to those of pilots in the standard training program. If the evaluation results are positive, a further specialized training program will be designed to train pilots how to interpret superimposed symbology, shift visual attention, compensate for the loss of peripheral cues, and adapt to the distortions and resolution limitations of current and projected helmet-mounted night-vision systems.

TECHNICAL CONTACT: Sandra Hart, ARC (415) 694-6072

HEADING CONTROL WHILE USING HELMET-MOUNTED DISPLAYS

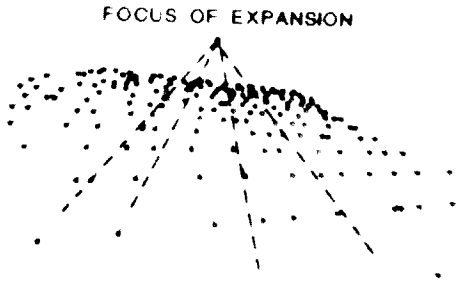
- PROBLEM:
  VISUAL INFORMATION ABOUT VEHICLE STATE IS AFFECTED BY SLEWING OF OFFSET, LIMITED APERTURE, HEAD-COUPLED SENSORS

- OBJECTIVE:
  DETERMINE PILOTS' ABILITIES TO MAINTAIN ALTITUDE AND HEADING WHILE SIMULTANEOUSLY TRACKING OFF-AXIS TARGETS

- APPROACH:
  - THEORETICAL ANALYSIS OF MOTION FLOW FIELDS TO PREDICT PILOT PERFORMANCE
  - EMPIRICAL EVALUATION IN ADVANCED HELICOPTER SIMULATOR USING HONEYWELL HEAD-TRACKING SYSTEM (IHADSS)

- RESULTS:
  - OFF-AXIS TRACKING TASK AFFECTS HEADING/ALTITUDE PERFORMANCE
  - HEADING, RATE, AND ALTITUDE INFORMATION ON HUD INADEQUATELY REPRESENTS VEHICLE STATE DURING OFF-AXIS TRACKING WITH IHADSS

• VISUAL FLOW FIELDS



PURE TRANSLATION
(MOTION CUES GIVE HEADING AND ALTITUDE INFORMATION)

TRANSLATION + SENSOR YAW
(HEADING INFORMATION IS DISTORTED DURING TRACKING)

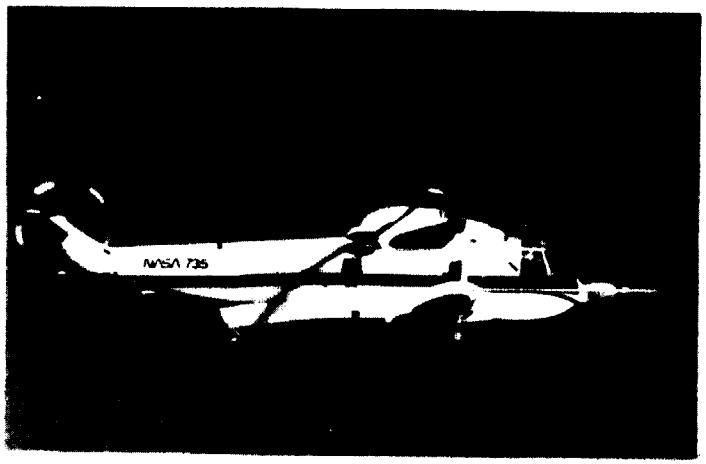
Validation of Workload Measures

The Workload Research Program has been completed, and a number of workload measures have been developed and tested. An expert system is being developed to assist in selecting and applying appropriate workload measures for specific tasks and environments. Several review articles have been completed to summarize and integrate numerous national and international conferences devoted to the topic of workload. An annotated bibliography has been published, consisting of 242 articles, reports, and book chapters written by participants in the program. Significant support has been provided to the FAA and to the Army.

The workload measures developed at Ames have received wide usage during the past year by the Army, Navy, Air Force, in industry and in university research programs. For example, a study was completed in which the NASA-TLX rating scale was used to evaluate the workload imposed on pilots and controllers by alternative TCAS configurations. NASA-TLX was also used by NASA-LaRC to compare alternative flight-director designs.

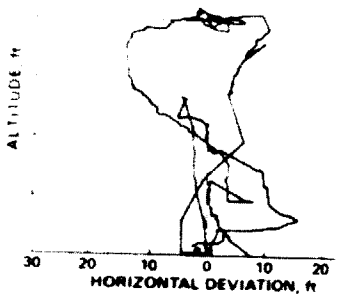
TECHNICAL CONTACT: Sandra Hart, ARC (415) 694-6072

INFLIGHT VALIDATION OF NASA WORKLOAD MEASURES



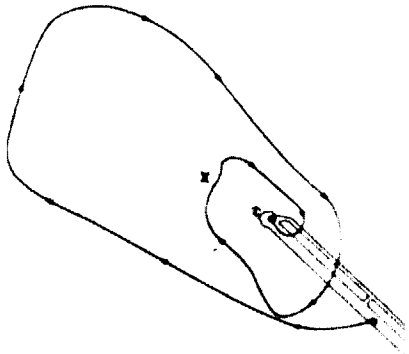
HOVER PERFORMANCE

IN GROUND EFFECT:
WORKLOAD RATING: 48

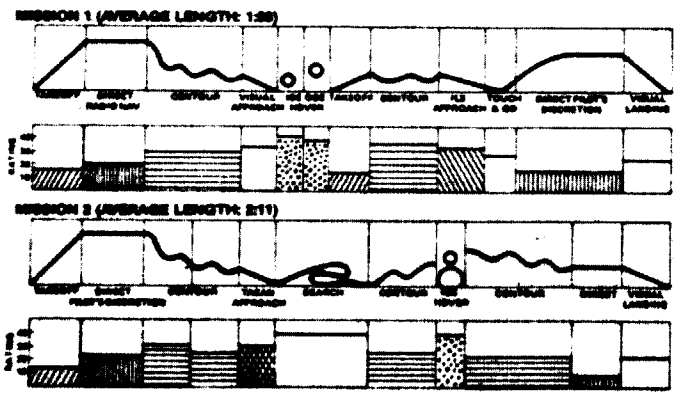


SEARCH FOR GROUND TARGET

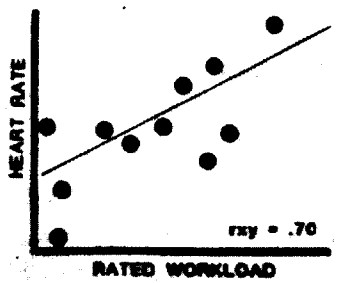
WORKLOAD RATING: 41
TIME TO FIND TARGET: 7 min



INFLIGHT WORKLOAD RATINGS



HEART RATE vs RATED WORKLOAD
(MISSION TWO, 11 SEGMENTS)



Mental State Estimation

This research effort broadens the scope of previous workload research in that it focuses on particular mental states of the human operator rather than a global measure of workload. Mental States that are of interest include overload, boredom, fatigue, stress, confusion, etc. The Mental States will be indexed through patterns of physiological responses, such as EKG, EEG, EDR, Scan Behavior, etc. Mental State Estimation is a developing technology whose time has come.

One goal of this program is to develop the technology to unobtrusively track both the cognitive and emotional experience of crews in the flight deck environment on the basis of central nervous system, autonomic nervous system and skeletomuscular responses. The quantification of the Mental State will be very useful in the assessment of the impact of procedures, controls, and displays on the flight crew. This technology will be useful for researchers in government and industry. Another goal is to further develop the technology in such a manner that information about crew Mental State can be used for the allocation of tasks between the "electronic crew member" and the human crew.

The significance of this research is that it will establish a criterion set of measures to index Mental State thus providing an effective control/display and flight system evaluation tool. It would also provide the technology needed to perform dynamic task allocation and to enhance the quality of the man machine interface. A fully interactive biocybernetic flight control system would employ instantaneous Mental State assessment to keep the system and crew informed of the crew's capabilities in real time. More sensitive and reliable human response measurement methods than are currently available are required to meet the requirements of future aerospace systems research.

Recent results obtained in this program include the establishment of the physiological pattern for the Boredom Mental State. In addition evoked potentials and scan behavior have been used in display evaluation tests. In June 1987 a workshop on Mental State Estimation which involved government/university/industry researchers was conducted.

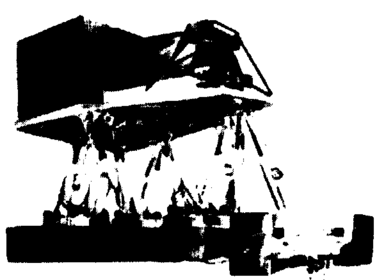
Future plans of this effort include: define Mental States in the flight deck environment; develop a protocol to psychophysiologically profile test subjects in order to know how they will typically respond in particular situations; and develop a Mental State Estimation Protocol Guidebook.

TECHNICAL CONTACT: Randall L. Harris, Sr., LaRC (804) 865-4685

CREW STATE AND FLIGHT SYSTEM STATUS MONITOR

2001

1987



Validated Wind Shear Model Through Comparison With DFW/Delta Airlines Microburst Event

A wind-shear model, based on the atmospheric physics associated with microburst phenomena, was developed earlier in the program. Once initialized with a set of ambient atmospheric conditions, followed by an arbitrary triggering disturbance, the model, assuming that the initial conditions were conducive, spontaneously generates the full-state output for the microburst, including, for example, the vector wind field and radar reflectivity as a function of X, Y, Z, and time. The objective of this research effort was to provide a validated data-set, generated by the model, corresponding to a specific microburst occurrence.

On August 2, 1985, a Delta Airlines L-1011 encountered a microburst-induced wind shear and crashed during a landing approach at the Dallas-Fort Worth airport. Extensive analysis of that accident by numerous investigators resulted in the development of a great deal of information concerning atmospheric conditions just prior to the occurrence of the microburst, as well as information concerning the microburst event itself, such as the outflow propagation-rate at ground level and the existence and location of rain and hail. This atmospheric information was used to initialize the model, which then generated the full-state output of microburst parameters, which were, in turn, compared with information deduced from the actual event.

Excellent agreement was obtained between the model outputs and corresponding data from the microburst. An example of this agreement is shown in the figure, which is a comparison of the observed and predicted outflow diameter of the microburst at ground level, as it propagated from a diameter of zero to approximately six miles over a period of seven-to-eight minutes.

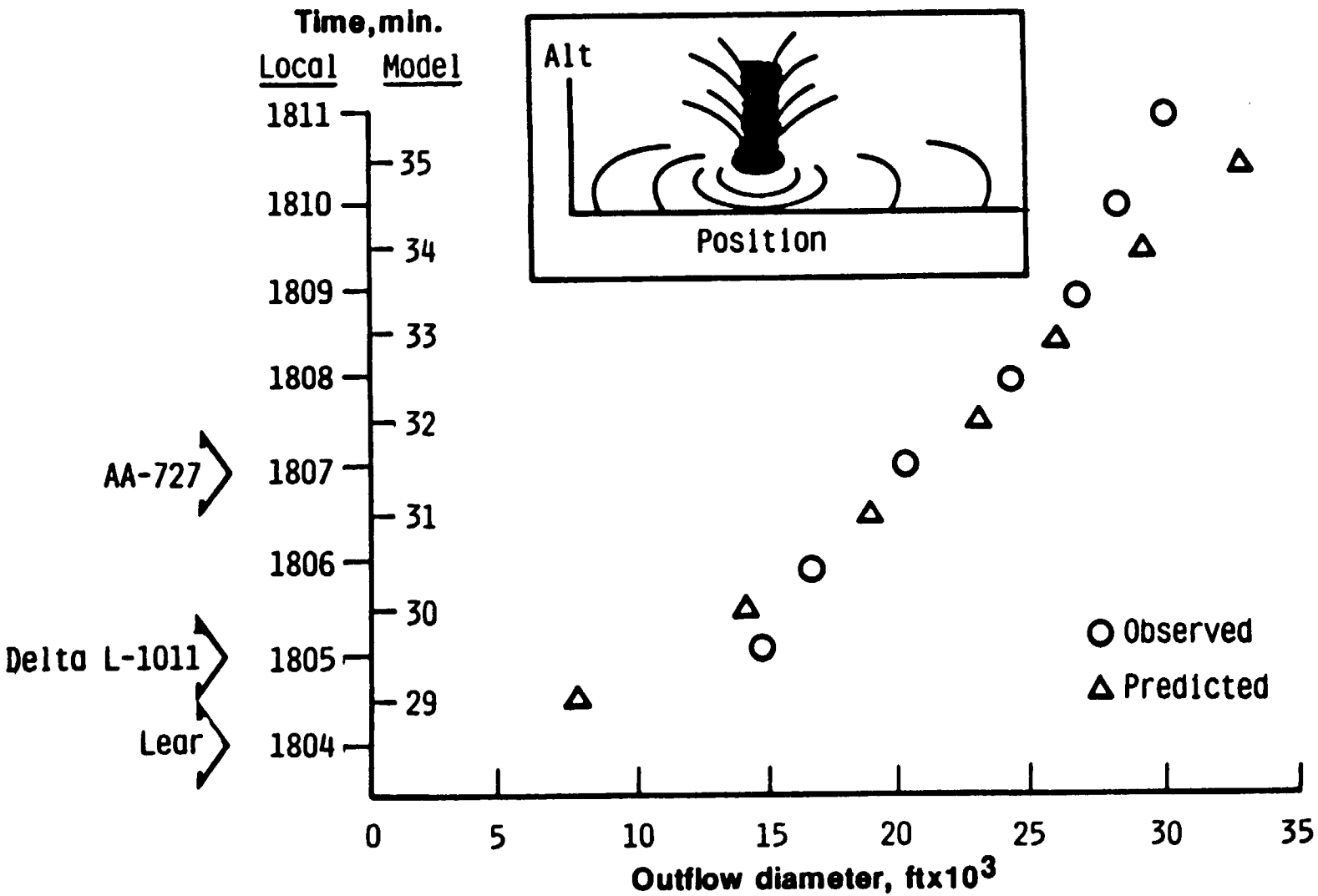
Having thus validated this data-set, one can, with a considerable degree of confidence, employ this data set in a host of research, development, and training applications which require the high resolution, expansive volume, and time variant characteristics of the microburst state variables.

This validated data set has been widely disseminated and is being utilized by Boeing, Douglas, Lockheed, Sperry, the airlines, and within NASA.

TECHNICAL CONTRACT: Dr. Roland L. Bowles, LaRC (804) 865-3621

DFW MICROBURST EVENT vs MODEL PREDICTION

(Outflow expansion rate)



Manned Vehicle Simulation Research Facility (MVSRF)
FY87 Accomplishment Highlights

The MVSRF is capable of simulating the Air Traffic Control workstations and functions, operations and flight dynamics of a B-727 cockpit, and special operations of an advanced cockpit flight deck of a generic, "glass cockpit", future transport aircraft. This facility supported the following tests and evaluations:

1) Traffic Collision and Avoidance System (TCAS), an inflight detection and flight direction system, was used to evaluate full-mission crew performance under different flight conditions. Crews from United Airlines and Northwest flew different scenarios with and without TCAS so that operational effectiveness of TCAS could be obtained.

2) As part of a study of workload measurement in support of FAA, researchers from Boeing and McDonald-Douglas evaluated different kinds of workload measurement methods, such as subjective ratings, physiological measures, performance measures, and analytical techniques. Pilots from cooperating airlines flew both long and short duration flights during which time these different measures were employed. These tests were extended into FY 1988.

3) An evaluation of the Microwave Landing System (MLS) at four airport sites (simulated) was done with the B-727 simulator. Researchers tested crews using a MLS curved landing approach in the New York TRACON (JKF, LGA, EWR) and a back-azimuth-guided missed approach at LAX. Both the FAA Administrator and the International Civil Aeronautics Organization were briefed on the results.

4) A study of display-based data link with ATC communications was performed in the advanced cabin simulator. Additional studies were scheduled for FY 1988.

5) A study of how different kinds of information can and are used for inflight decision-making was performed using the advanced cabin simulator. From data collected during the simulations and from interviews of pilots, an initial determination was made about requirements of an expert system pilot aid. Additional tests were scheduled for FY 1988.

TECHNICAL CONTACT: Charles E. Billings, ARC, (415) 694-5718

MANNED VEHICLE SYSTEMS RESEARCH FACILITY

Human Factors - Space

The objectives of the space human factors research and technology program are to provide a technology base for intelligent operator interfaces, especially with autonomous subsystems, and to develop a new generation of high performance space suits, gloves, and tools/end effectors to meet the requirements of advanced space missions. The technology base is intended to provide increased productivity, efficiency, and safety in complex manned operations within automated onboard systems and extravehicular activities (EVA) environments.

Crew station research is the first of two major areas. Development of methods for the astronaut to supervise, monitor and evaluate the performance of robotic systems, other space subsystems, and orbital vehicles are key areas of research. Fundamental understanding of the human visual and information integration capabilities provides a technical basis to develop mathematical, anthropometric, and graphical models of human interactions with space systems and equipment. The capability to perceive, evaluate and control robotic assistants, computer-generated images of actual systems and space structures, and to interact with such assistants, systems and structures, via computer models, has achieved an initial feasibility under the name virtual workstation research. A large scale mock-up of the viewing cupola of the Space Station provides the means to study the effects of a 90-minute cycle of light-darkness on windows, on displays and on the astronaut's tasks in the cupola for proximity operations.

The second major area is development of a new extravehicular activity (EVA) space suit and gloves. A major milestone was accomplished with the completion of the AX-5 hard suit and its initial test for mobility and ease of donning and doffing. This suit is a prime candidate for use in the Space Station and allows the astronaut to don the space suit without extensive pre-breathing of oxygen. It is being tested and evaluated against a second new EVA suit, ZPS Mk. 3, which has both hard metal and fabric features. Also under research and technology development is a project to study and develop end effector mechanisms whereby the EVA-suited astronaut can control and supervise robotic assistants. An important feature of this is a force feedback capability whereby the user receives feedback of the proportional amount of force being applied by the robotic end effector to the object being grasped. Also, the human factors research program includes development of new methods to display information on the space suit's visor to give to the astronaut a capability to interact with displayed information by means of voice commands.

Emphasis in the space human factors research program is placed on technology baseline studies and development of methods, techniques and data to support productive and safe operations by the astronaut and crew as they interface with complex systems, advanced automation, and robotic assistants.

PROGRAM MANAGER: Dr. James P. Jenkins
NASA/OAST/RC
Washington, DC 20546
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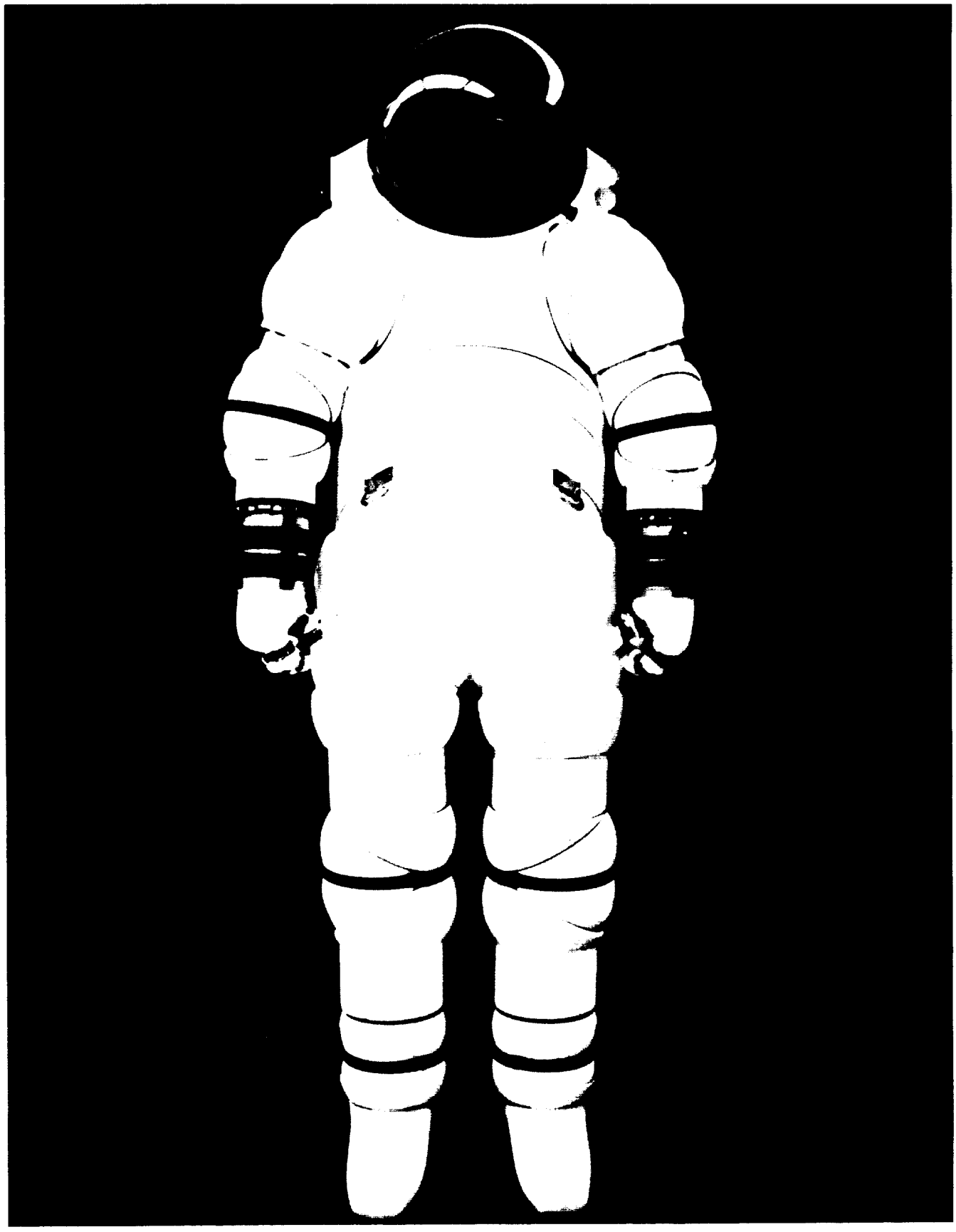
AX-5 Hard Space Suit and Neutral Buoyancy Test Facility for EVA (NBTF)

The Space Station represents a significant departure from previous space missions in the degree to which EVA will be a routine part of operations. For extended EVA, space suits must be capable of supporting pressures approaching one atmosphere while maintaining needed levels of mobility. They must also offer the astronaut greater degrees of protection from debris, micrometeorite penetration, chemicals, radiation, and thermal loads. Joint, bearing, and seal technologies developed at Ames have been incorporated into the current Shuttle suit. The new AX-5 hard suit incorporates many of these older concepts, along with innovative sizing techniques. The AX-5 is designed to operate at atmospheric pressure, to maintain high levels of joint mobility, and to provide excellent protection and comfort.

A small neutral buoyancy test facility (NBTF) has been completed and man-rated. The NBTF will provide a low-cost capability to evaluate suit and glove performance, as well as to support EVA systems research, hardware design, and evaluation.

TECHNICAL CONTACTS: Herbert Vykukal, ARC (415) 694-5386
Bruce Webbon, ARC (415) 694-5385

AX — 5 HARD SPACE SUIT



Human Capabilities in EVA

The extravehicular activity (EVA) space suit significantly impacts human performance. It restricts the range of motion of the astronaut inside it, and affects the amount of force he or she can apply to an object. Quantitative data on these effects are needed for planning EVA. If the capabilities of EVA astronauts can be predicted from 1-g data, realistic tasks and timeliness can be more easily planned.

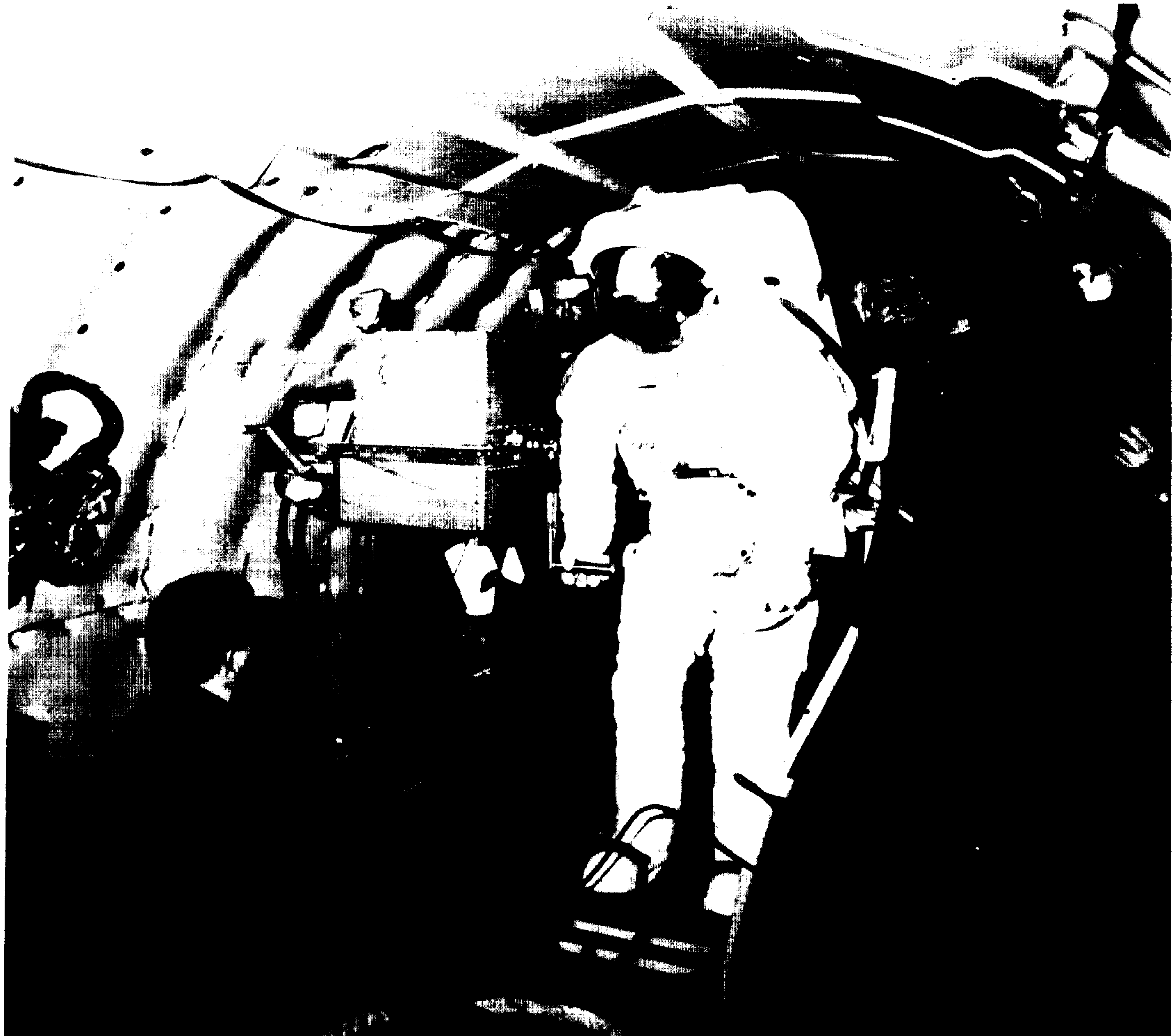
This year, several studies have been conducted to evaluate the effects of the EVA suit on reach and strength. Data giving the reach envelopes of people in shirt sleeves and in pressurized suits have been collected for a small female and a large male. This data was collected in the Anthropometries and Biomechanics Lab in 1-g. In another reach study, it was found that a subject had a greater 1-g reach envelope in a prototype Zero-Prebreathe suit pressurized to 8 psi than in the Shuttle suit at the standard 4.3 psi.

Strength studies have shown that a pressurized glove cuts the hand grip strength of an astronaut to about 57% of the bare hand grip strength. More complex relationships between suits and strength have appeared in data collected in the brief periods of 0-g induced by parabolic flight. Here the astronauts perform both single joint motions and typical EVA tasks such as wrench-turning while in foot restraints and pressure suits. In some cases the torque applied was less than that in shirt sleeves; in other cases it was greater. However, effects among astronauts were consistent.

Further studies will be conducted to collect additional strength data in the lab, in parabolic flight, and in the neutral buoyancy facility. Modification of the reach measurement system suitable for the simulated 0-g environments would allow strength and motion data to be collected simultaneously.

TECHNICAL CONTACT: Barbara Woolford, JSC (713) 483-3701

STRENGTH DATA ARE COLLECTED IN ZERO G DURING PARABOLIC FLIGHT



Helmet Mounted Display Human Factors

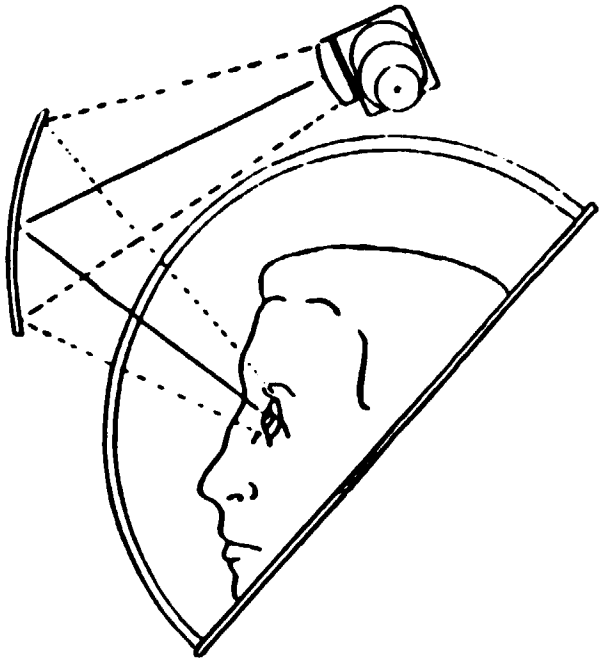
Extravehicular activity mobility units (EMUs or space suits) are self contained units in which the astronaut functions independently of the spacecraft. The suit environment parameters such as pressure, flow rate, and temperature are of extreme importance to the astronaut. Also, the astronaut requires the necessary information to perform his or her EVA task. Schematics of a satellite or the order of steps to be performed in a maintenance task may need to be referred to.

The current EMU relies on a twelve-character LED display and cardboard cuff checklists which require two hands to access. The helmet mounted display (HMD) is proposed as a performance aid to the EVA astronaut. The HMD would allow visual data--words, numbers, or pictures--to be displayed on an area inside the helmet. Two prototype HMDs are currently being developed. This task is designed to determine what information should be presented, and how it should be formatted and accessed.

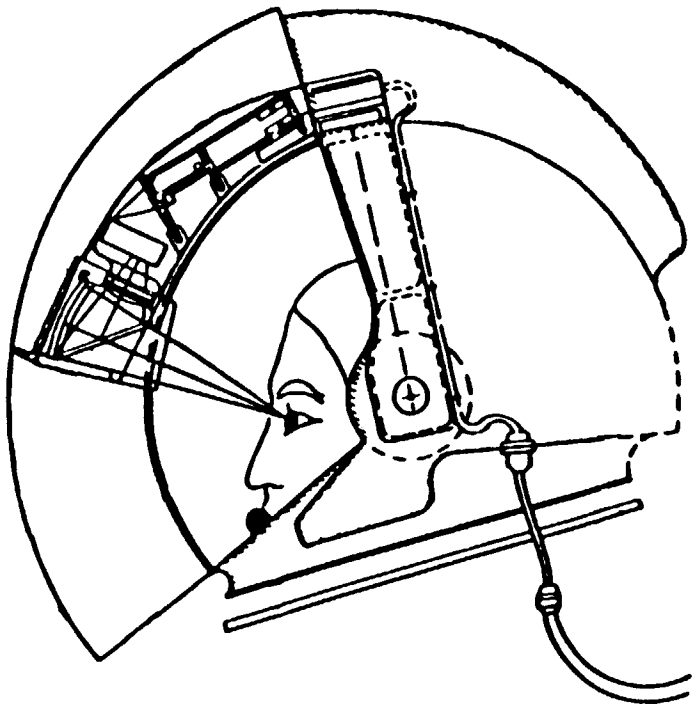
The natural access method is voice control, since dexterity is low in pressurized gloves and any keyboard or pointer scheme would not leave the hands free for the task being performed. Selection of vocabulary becomes a major human factors issue, since the words must be both physically discriminable to a voice analyzer, and easy for the astronaut to remember. A tree structured menu, in which one word selects the next menu, and only a subset of the total vocabulary is active at one time, is being investigated. Such a menu design would drive the structure of the software controlling all the displays and suit functions. The format and layout of the data, as well as its nature, are also being investigated. The ease of use and the preferences of astronauts for graphical, tabular, and video data in different contexts will be explored.

TECHNICAL CONTACT: Barbara Woolford, JSC (713) 483-3701

HMD DESIGN CONCEPTS



WRIGHT-PATTERSON



HAMILTON-STANDARD

Virtual Workstation

Ames Research Center is developing the Virtual Workstation which consists of a wide field-of-view stereo helmet mounted display, a magnetic head tracker, a custom video processor, fiber optic gloves, magnetic gesture trackers, voice input/output, and three dimensional sound. The system is being developed to enable greatly improved presentation of highly spatial information; to simulate workstations, cockpits, and module interiors; to enable high fidelity telepresence; and to enable virtual exploration of planetary data.

The Virtual Workstation will provide the human interface to enable telepresence, the projection of human capability to remote locations. Human presence provides the most flexible and refined capability to collect information and manipulate the environment of any system ever devised, and it will be a vital element of Space Station, Moon base, and Mars exploration missions. While Extra-Vehicular Activity (EVA) will account for much of the human presence,and automated robots will assist in many chores, telepresence will provide a third essential capability.

Virtual exploration of planetary data will be made possible by the integration of image data from planetary missions into a computer graphics database. Planetary environments will then be recreated from their data. By use of the Virtual Workstation the user can explore the planets as environments, not merely as pictures. This application awaits advances in planetary data processing.

Accomplishments to date include the design and implementation of the Virtual Visual Environment display (VIVED), increased resolution and use of new diamond-shaped pixels, printed circuit fabrication of the video display processor, integration of fiber optic gloves, construction of a desktop system using boom mounted cathode ray tubes, and initial implementation of voice input/output and 3D sound.

Future plans include achievement of the Initial Operating Configuration (IOC), in which the host computer, graphics processor, and the elements of the Virtual Workstation interface are integrated in a stable configuration. In cooperation with NASA-Ames, NASA's Jet Propulsion Lab (JPL) is developing a highly dexterous anthropomorphic end effector, in essence, a remote hand, wrist, elbow, and shoulder. Telecommunications will be added to the Virtual Workstation, and high fidelity dexterous telepresence will be demonstrated within several years. In a second JPL/ARC effort, the Virtual Workstation will be used to provide an alternate operator interface in telerobotics supervisory control. Resolution will be increased with both rectilinear arrays and non-linear pixel mappings. Workstations and module interiors will be simulated, and multi-member crew interaction will be implemented. Spinoffs include visualization of computational fluid dynamics calculations (virtual windtunnel), and use in rotorcraft helmet mounted display research.

TECHNICAL CONTACTS: Michael W. McGreevy, ARC (415) 694-5726
Scott S. Fisher, ARC (415) 694-6789

HEAD-MOUNTED WIDE-ANGLE STEREOSCOPIC DISPLAY SYSTEM. The display system is controlled by operator position, voice and gesture developed for use as a multi-purpose interface environment. Interface for Telerobotics; management for space station information system.

Interactive Spatial Instruments and Proximity Operations Displays

Research in spatial perception is advancing from an understanding of the perception of simple dynamic patterns to an understanding of the basic human ability to perceive and control objects in three-dimensional space. Understanding the relation between perception and action is important to the design of advanced spatial instruments. A spatial instrument, in contrast to a spatial display, is enhanced geometrically or symbolically to improve its communicative functionality. Interactive spatial instruments will be increasingly important for manned space missions. Aerospace plane and other advanced spacecraft will require flight deck displays to support situation analysis, rapid decision-making, and real-time control. Proximity operations around the Space Station will require extensive interactive monitoring and control by crew members. Interactive spatial displays will be essential for space traffic control, EVA monitoring, and teleoperations.

A simulation of a proximity operations workstation has been developed which enables operators to control the movements of simulated vehicles. On the Space Station, for example, such a workstation would enable the crew to control the movements of orbital maneuvering vehicles. The crew can move the vehicles in six different directions on the multiscreen computer graphics simulator and can also see the vehicles from different angles. This simulator is being used to gather data on workstation design and human-machine interaction in a realistic task setting.

A workshop on "Spatial Displays and Spatial Instruments" was held from August 31 to September 3, 1987, at the Asilomar Conference Center under the joint sponsorship of the Ames Human Factors Research Division and the University of California, Berkeley, School of Optometry. This workshop brought together scientists, engineers, and practitioners from government, academia, and industry to focus on the theoretical understanding of pictorial communication.

TECHNICAL CONTACTS: Steve Ellis, ARC (415) 694-6147

APPROACH ALONG THE SPACE STATION'S VELOCITY VECTOR

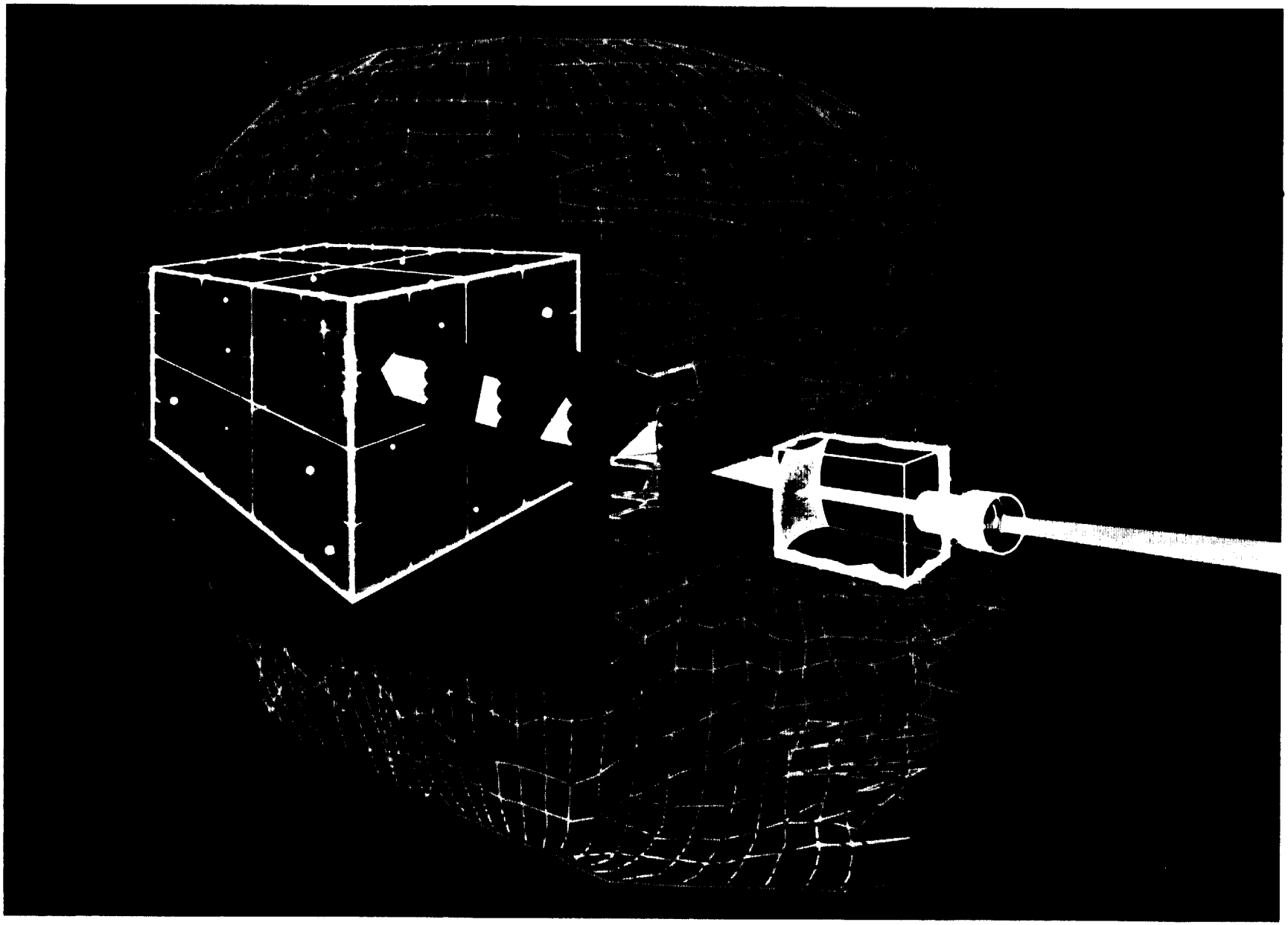
Computational Models of Human Vision

Human spatial perception is unequaled by any artificial system in its ability to monitor and guide intelligent behavior in dynamic environments. This research project is developing and refining rigorous models of the mechanisms responsible for the unique capabilities of human spatial perception. These models are beginning to provide the technology base for safe and effective manned space operations in complex task environments.

Understanding the unique properties of human vision, which depend upon the spatial distribution of receptor cells and the assignment of those cells to channels, may lead to improved aerospace displays for simulators, cockpits, and teleoperations, as well as improved autonomous vision and image processing systems. Unlike common video sensors, the human visual system has extremely variable resolution as a function of off-axis angle. Ames researchers have developed the only model for generating arrays which have the same sampling characteristics as the human retinal sampling array. This model is implemented as a computer program which runs on the Cray X-MP-48. This model and others based on properties of the human visual system exhibit a variety of surprising and desirable characteristics, including super-resolution, noise suppression, dynamic range compression, edge enhancement, and adaptive, reflectance-based image coding.

TECHNICAL CONTACTS: Albert Ahumada, ARC (415) 694-6257
Andrew B. Watson, ARC (415) 694-5419

THE SCHEMATIC HEAD: 1) A camera with the variable density characteristics of the human eye; 2) four planes representing the parallel channels of the visual cortex; 3) the distribution memory model.



Operator Function Models

Operator models provide a framework for knowledge, engineering, system design, and system evaluation. They also play an essential role in building intelligent interfaces. The Operator Function Model (OFM) project consists of three related activities: the development of an operator function model for complex automated space systems; the implementation of software tools for rapid prototyping of operator models; and the development and evaluation of expert systems capable of performing certain supervisory control tasks in automated space systems.

The operator function modeling methodology has been extended from manual operator activities to cognitive activities. OFMdraw, a rapid-prototyping tool, has been implemented on a Macintosh+ using Experintelligence and Exper's Interface Builder. OFMspert, an expert system based on the operator function model, is currently implemented on a PC-AT which communicates with the Georgia Tech Multisatellite Operations Control Center simulation. Initial evaluation of OFMspert indicates that the ability of the system to infer operators' intentions is good, and future validation efforts will focus on control capabilities, user interactions, and the implementation of an intelligent direct-manipulation interface.

TECHNICAL CONTACT: Everett A. Palmer, ARC (415) 694-6073

HUMAN-MACHINE INTERACTIONS RESEARCH

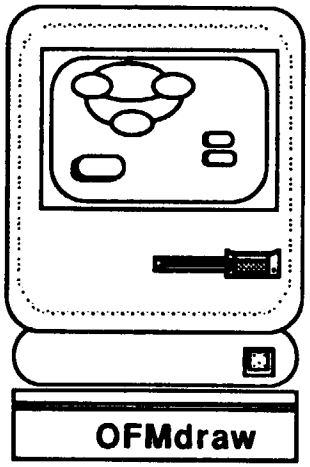
OPERATOR FUNCTION MODELS

OBJECTIVES

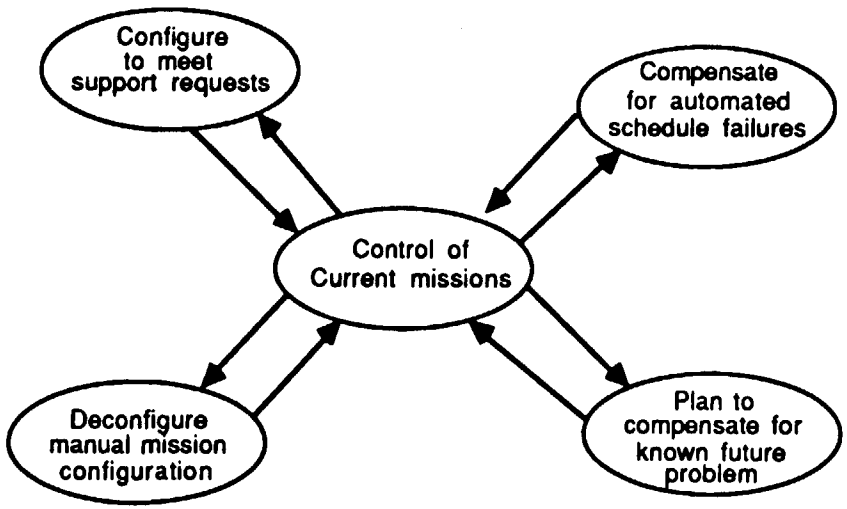
- METHODOLOGY FOR MODELING OPERATOR TASKS
- HF DESIGN AIDS FOR TASK MODELING
- OPERATIONS AIDS WITH IMBEDED TASK MODELS

APPROACH

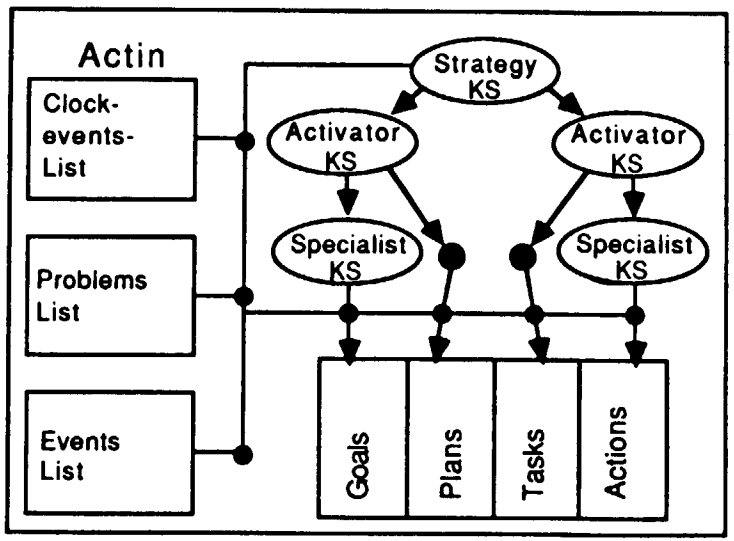
- DISCRETE TASK MODELS & EXPERT SYSTEMS
- INTENT INFERENCING + CONTROL
- ADAPTIVE FUNCTION ALLOCATION
- SIMULATION EVALUATION



MODELING TOOL



MODELING METHODOLOGY



OPERATOR ADVISOR

Human Interface with Expert and Planning Systems

Future intelligent software for management of space systems will perform both rule-based and model-based reasoning. To support communication between humans and intelligent software, the concept of explanation must be expanded beyond heuristics or rules to include system models. Since system schematics and related graphics and diagrams are commonly used to communicate about systems, methods are needed for effective use of such graphics in human interface with intelligent systems. Several aspects of this problem are being investigated by a university, industry and government team, representing several disciplines.

A cognitive theory of diagram comprehension has been developed for tasks in managing engineered systems, and guidelines for diagrammatic displays of engineered systems have been formulated. Studies are being conducted of alternative diagram formats, to test the theory and provide a basis for refining the guidelines. The studies indicate that diagnosis of malfunctions is aided by dynamic diagrams that show the topology, causal pathways, and internal states of system components. Future experiments will use diagrams of a device in a Space Station subsystem, and will investigate how various types of diagrammatic information help the operator infer or verify malfunctions.

Qualitative models of electrical and thermal systems are being developed, to support development of standardized model libraries for intelligent software systems. Fluids have been modeled as molecular collections, in order to reason about thermodynamic properties. Mixtures of device-centered and process-centered models of systems are being studied. Concepts of the role of qualitative models in several phases of intelligent computer-aided engineering and operation have been developed, to provide a context for the theoretical work. Future work will include developing fault models and exploring mixtures of qualitative and quantitative representation. The work will culminate in building prototype qualitative models of elements of Space Station subsystems.

Commonsense system models used by engineers in failure management are being analyzed, and tools are being developed for building graphical models for use in intelligent failure management systems. An initial prototype has been developed of a qualitative simulation tool for graphically representing mental models of systems. An analysis has been completed of how expert engineers develop failure management systems from device design information. A paper describing the results of this analysis is in press in an IEEE journal. Work on the qualitative modeling tool is continuing.

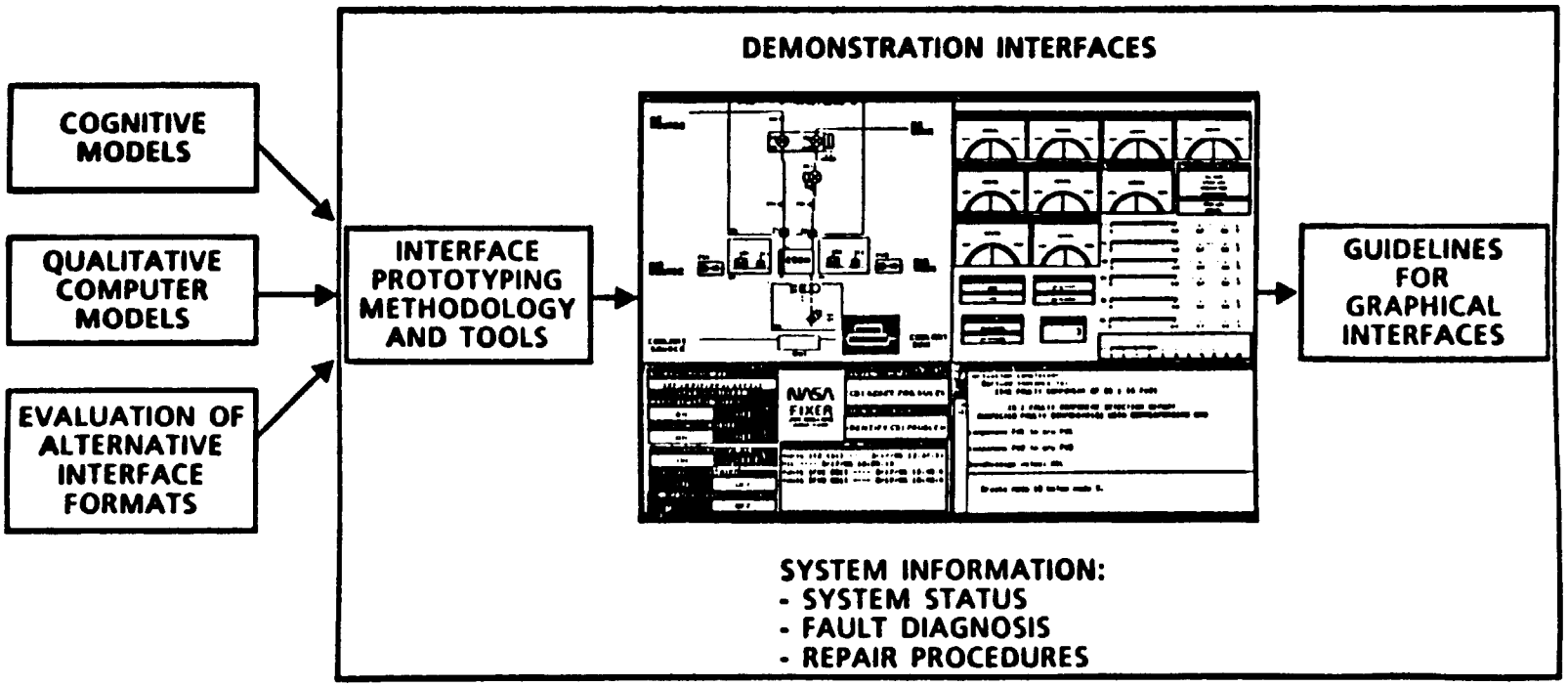
Work has begun on developing software tools to support integrated development of model-based intelligent management software and diagrammatic interfaces. Man-machine communication tasks are being analyzed in the context of space station intelligent systems. Next year, prototypes will be built of expert systems with diagrammatic interfaces for space operations scenarios. These will illustrate how graphical displays should be designed to aid development and operation of intelligent systems for failure management. Methodology and tools for designing graphical interfaces for intelligent systems will also be prototyped.

TECHNICAL CONTACT: Jane T. Malin, JSC (713) 483-2046

HUMAN INTERFACE WITH EXPERT AND PLANNING SYSTEMS

SIGNIFICANCE

- GRAPHICAL AIDS FOR DEVELOPMENT AND TESTING OF EXPERT SYSTEMS FOR DIAGNOSIS AND REPAIR OF ELEMENTS OF SPACE SUBSYSTEMS
- GRAPHICAL AIDS FOR MAN-MACHINE COOPERATION IN OPERATIONS
  - INTELLIGENT AUTOMATED FAULT DIAGNOSIS AND REPAIR PLANNING
  - EXPLANATION, REPORTS, AND TRAINING



NASA

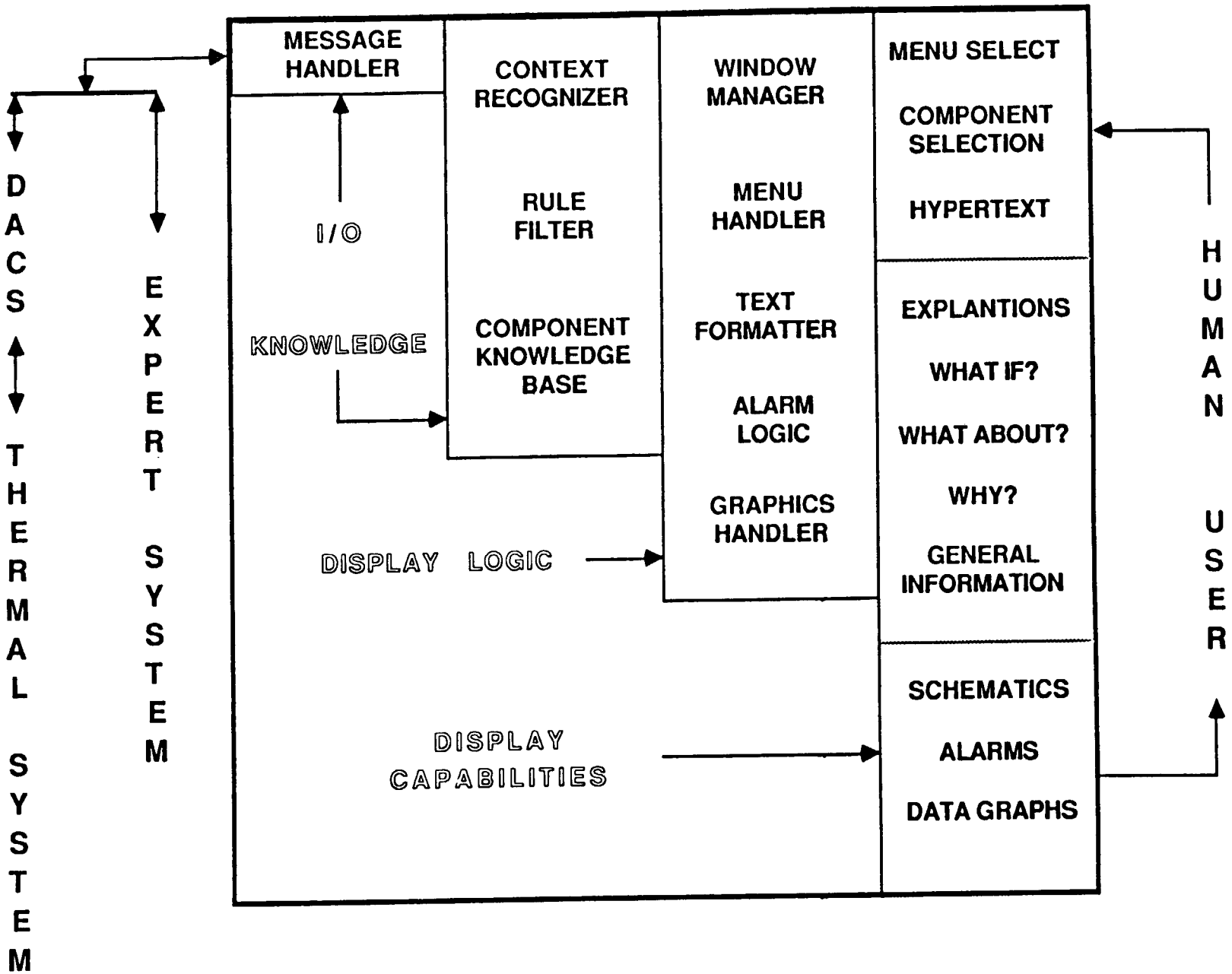
Thermal Expert System Human Interface (HITEXS)

The human operator plays an indispensable role in the safe and efficient maintenance and control of advanced automated systems. As automation evolves, it is expected that fewer operators will maintain and supervise systems of increasing complexity. In aeronautics a pattern of human error has been observed which is characterized by a decline in situation awareness and a failure to generate appropriate expectations about the behavior of automated systems. Similarly, in the design and evaluation of automated space systems it is necessary to address basic issues concerned with human error, attention management, information management, maintenance of situation awareness, and accurate communication of intended actions. The integration of operator interfaces with advanced automated systems is costly and time-consuming. New methods need to be developed for the evaluation of interface design options during the early stages of system prototyping.

This research effort aims to develop a NASA/university research team capable of delivering a technology base for operator-interface design in advanced automated systems. The effort is focused on the needs of the Systems Autonomy 1990 Demonstration Project and outyear demonstrations. The following short-term deliverables have been identified: a task model of the thermal control system based on the Georgia Institute of Technology finite-state methodology; a computerized task analysis tool to complement the task model; a comparative evaluation of three different cognitive modeling methods for the thermal control system operators; a task-oriented interface specification system for the thermal control system; and an operator-oriented qualitative model of space-borne process-control applications, designed to facilitate causal explanations.

TECHNICAL CONTACT: Roger W. Remington, ARC (415) 694-6243

HITEXS INTERNAL STRUCTURE



Crew Station Human Factors

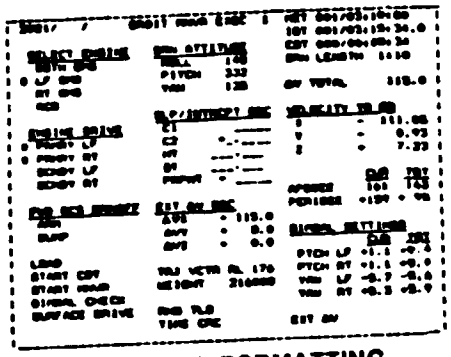
The purpose of the Crew Station Human Factors program is (1) to examine human-computer interactions (HCI) and related display and control technologies and (2) to determine their efficient incorporation into space crew workstations. The study and application of these aspects of human interactions with crew stations are designed to increase productivity and safety during the on-orbit conduct of crew activities. The program involves research, followed by the application of the results of that research into both human factors requirements for spacecraft and workstation-related designs.

The Crew Station Human Factors research program has been developed to address topics with both immediate application to current spacecraft crew station design and the longer-range enhancement of knowledge about human factors in the space environment. The research has included experiments and studies on (1) the effect of formatting computer displays on the performance of experts and nonexperts, (2) the use of multifunctional controls in crew activities, and (3) the design features required for the efficient use of computers to display crew procedures. The products of this research are technical reports and demonstrations of the use of these advanced technologies. The research has been conducted in the Human Factors Laboratory (HFL) at JSC.

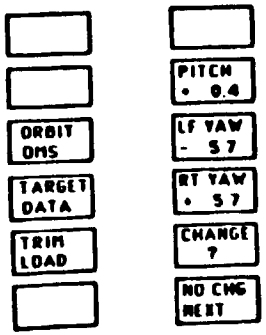
The application of this research has grown out of specific needs for human factors input in two areas related to spacecraft crew workstations -- guidelines for a spacecraft Human-Computer Interface and the functional design of spacecraft workstation systems. The Human-Computer Interface Guidelines address: (1) the display of information required by a system user; (2) the design of real-time interactions between a user and computer in the spacecraft environment; (3) the inputs by the user for text, graphics, and the control of computer functions; and (4) techniques for evaluating human-computer interfaces. The workstation system design centers around the layout of functions to promote productivity in the use of workstations through identifying functional requirements, performing analyses, and developing concepts. The products of these efforts are guidelines, prototypes of human-computer interfaces and workstations, and mockups.

TECHNICAL CONTACT: Dr. Marianne Rudisill, JSC (713) 483-3706

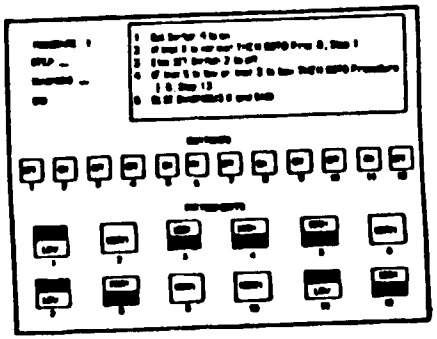
CREW STATION HUMAN FACTORS



DISPLAY FORMATTING

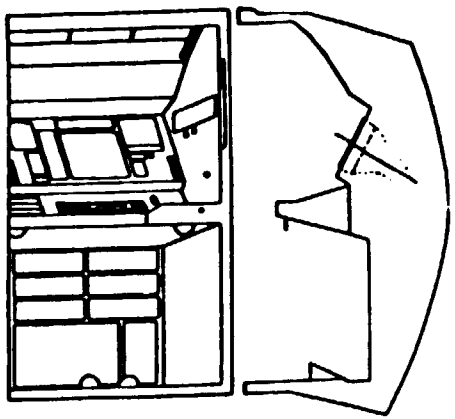


MULTIFUNCTIONAL CONTROLS

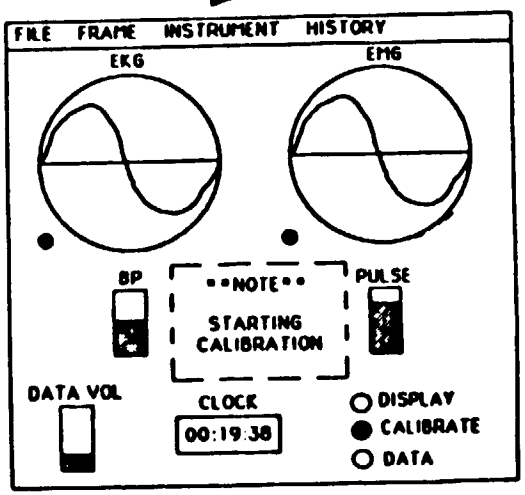


ELECTRONIC CHECKLIST

RESEARCH ON HUMAN-COMPUTER INTERACTIONS



WORKSTATION SYSTEM DESIGN



SPACECRAFT HUMAN-COMPUTER INTERFACE

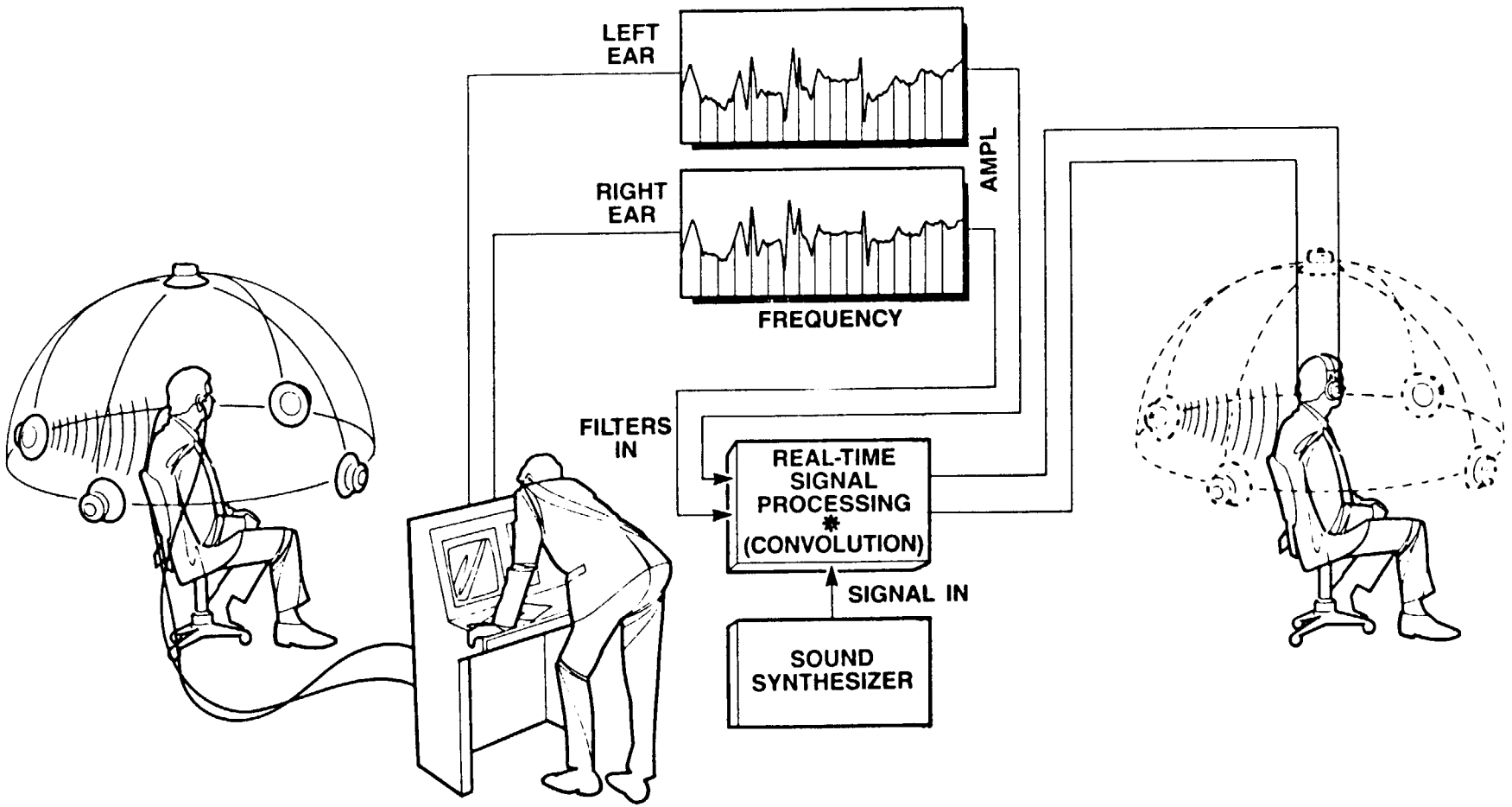
Three-Dimensional Auditory Display

The goal is to develop and validate the psychophysical theory required to synthesize three-dimensional, spatially localized acoustic cues in real time. A three-dimensional auditory display will be valuable in any situation where an operator's awareness of his spatial surroundings is important. For example, this technology is required for the VIEWS project which allows the operator to explore and interact with a synthesized or remotely sensed world.

Ames Tech Utilization has conducted a market survey to explore commercial interest in a three-dimensional auditory display. A contract is in place for the design of the required special-purpose signal-processing hardware. Researchers at the University of Wisconsin have completed psychophysical data collection and analysis based on measured characteristics of the human external ear. A psychoacoustics laboratory has been established at Ames for the off-line simulation and evaluation of the synthesis technique.

TECHNICAL CONTACT: Elizabeth Wenzel, ARC (415) 694-5716

3-D AUDITORY DISPLAY:
SYNTHESIS TECHNIQUE



PINNAE (OUTER EAR) RESPONSES MEASURED WITH PROBE MICROPHONES

PINNAE TRANSFORMS DIGITIZED

SYNTHESIZED CUES

N89-18406

Sensor Technology

The objective of the Sensor Technology Program is to provide necessary expertise and technology to advance space remote sensing of terrestrial planetary and galactic phenomena through the use of electromagnetic and electro-optic properties of gas, liquid, and solid state materials technology.

The Sensor Technology Program is divided into two sub-programs: a base research and development part and a Civil Space Technology Initiative (CSTI) part. The base research and development consists of research on artificially grown materials such as quantum well and superlattice structures with the potential for new and efficient means for detecting electromagnetic phenomena. Research is also being done on unique materials and concepts for detector components and devices for measuring high energy phenomena such as UV, x- and gamma rays that are required observables in astrophysical and solar physics missions. The CSTI program is more mission driven and is balanced among four major research and development disciplines: (1) detector sensors; (2) sub-millimeter wave sensors; (3) LIDAR/DIAL sensors; and (4) cooler technology. The first discipline plans to develop large spatial imaging format arrays in the near (1 - 30 micrometers wavelength) and far (30 - 200 micrometers wavelength) infrared portions of the electromagnetic (EM) spectrum. These goals are crucial to enable space-borne remote sensing for the various Terrestrial, Planetary, and Astrophysical missions. The submillimeter discipline is dedicated to developing the technology to enable heterodyne receiver instruments for remote sensing in the 300 to 3,000 GHz frequency regions of the EM spectrum with a focus on developing local oscillators, frequency mixers and quasi-optical technology in this region. Backward wave oscillators, lasers, and quantum well devices may also have potential as oscillators. In the third area the acronym DIAL/LIDAR (DIAL means Differential Absorption LIDAR while LIDAR means Light Detection and Ranging) consists of research on techniques for enabling active remote sensing in which a coherent source such as a laser is used to probe the environment. Research is concentrated on technology for obtaining tunable, frequency stable, and pure space qualifiable lasers. Finally, in the last discipline research is being done on technology to enable cryogenic coolers in the Kelvin to sub-Kelvin temperature regions in support of the efforts in the detector and submillimeter wave sensor thrusts. Work includes research on various cooler concepts such as the pulse tube, adiabatic, Helium 3, and zero-gravity refrigerators and their corresponding component development.

PROGRAM MANAGER: Martin M. Sokoloski
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Washington, DC 20546
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$Ti:Al_2O_3$ (Titanium Doped Sapphire) Laser Development

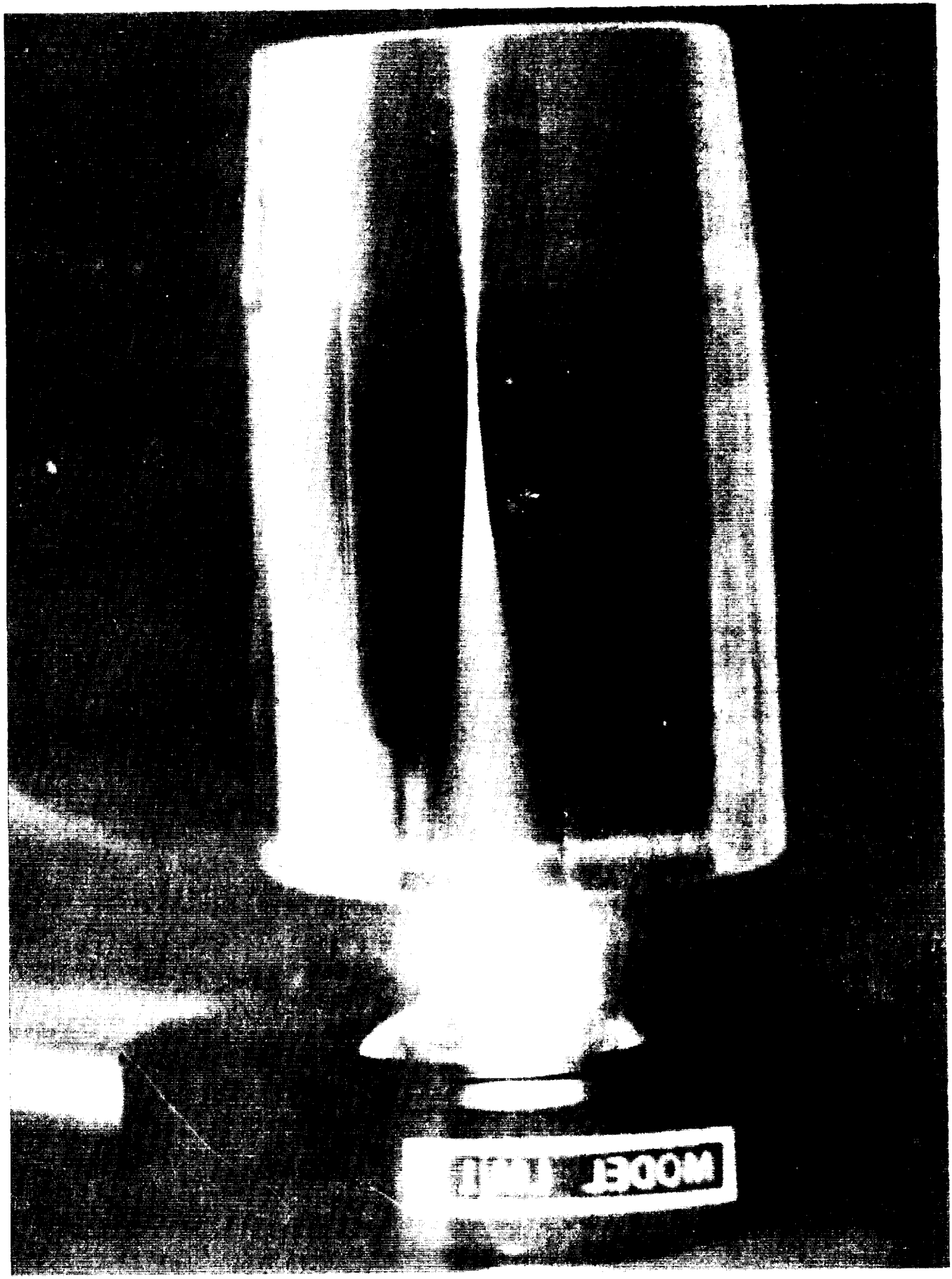
A major goal of the Active Sensing Research Program within OAST is to develop an all solid-state tunable laser transmitter in the near-infrared. Such a system would fulfill many of the scientific needs of the Space Station EOS polar platform. Specifically, a system tunable over the 0.72 to 0.95 micron range could access the water vapor bands around 0.73 and 0.94 microns as well as bands at 0.76 microns. Pressure and temperature profiles could be derived from the latter. In response to future NASA needs in active sensing technology, a goal has been established to develop an all solid-state laser tunable over the spectral region from 0.72 to 0.95 microns, with a spectral bandwidth of approximately 1.0 pm and a wall plug efficiency of better than 3 percent. A potential electrical to optical efficiency for a diode laser pumped, frequency doubled, Nd laser of 10 percent has been assumed. Given the desirable properties of $Ti:Al_2O_3$ (such as high gain and wide tuning bandwidth) a conversion from the frequency-doubled Nd laser output to the tunable near-infrared source appears feasible. Such conversion efficiencies have been demonstrated in the laboratory.

Work has concentrated this year on the development and understanding of the narrow spectral bandwidth operation of the oscillator and the demonstration and understanding of the $Ti:Al_2O_3$ amplifier. A twofold approach has been utilized to achieve narrow spectral bandwidth oscillator operation. Based on last year's results of injection locking with a narrow spectral band dye laser, injection locking using a laser diode was attempted and has been achieved, thereby utilizing technology compatible with the eventual application. Single-frequency operation was achieved by designing the laser to operate in a ring resonator. Such a resonator eliminated the spatial hole burning effects associated with a Fabry-Perot resonator. For wavelengths where a laser diode for injection locking is not available, a self-injection locking scheme was successfully implemented. In this concept, a single oscillator is operated sequentially in two resonators. Narrow linewidth performance is achieved in the first interval resonator by having a long pulse evolution time. Before the energy reaches a high level, the oscillator is switched to the second resonator where efficient energy extraction can occur. In addition, the latter method minimizes the risk of optical damage on the relatively sensitive line narrowing elements. With this scheme, a 2.0 pm spectral bandwidth was demonstrated.

Laser amplification using $Ti:Al_2O_3$ has been demonstrated and a comprehensive laser amplifier model has been developed. Initial experiments have demonstrated an amplification factor of 2.0. An amplifier model which accounts for such refinements as loss at the laser wavelength, nonuniform population inversion in both the transverse and longitudinal directions, nonuniform incident laser energy as well as spatial and temporal pulse distortion has been developed. Correlation of the model with experiments is proceeding.

TECHNICAL CONTACT: Dr. N.P. Barnes, LaRC (804) 865-3761

CHARACTERIZATION OF Ti:AL_2O_3 LASER MATERIAL

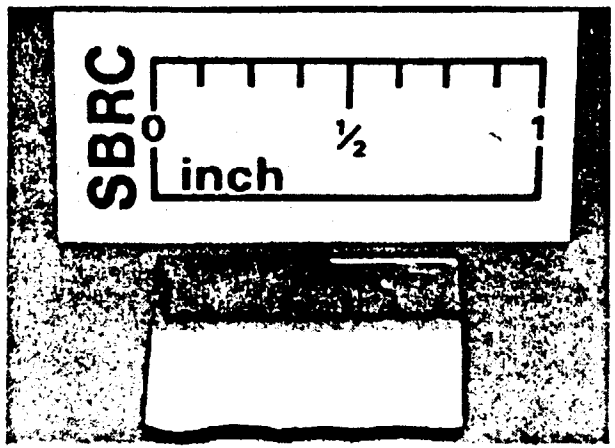


HgZnTe Materials and Device Development

A major goal of the HgZnTe Materials and Device Development Program is to develop infrared materials and sensors for atmospheric science studies in the Near and Mid IR spectral region. Sensing systems based on HgZnTe detectors will satisfy many of the scientific requirements for NASA's low Earth orbit limb scanners, for the space station and for the Eos Polar Platform. A major program goal is to replace HgCdTe devices which suffer from poor reliability and short lifetimes. Theoretical studies and experimental measurements have demonstrated that HgZnTe has stronger atomic bonding and is a harder more durable material than HgCdTe. Also the electro-optical properties of HgZnTe are comparable to and in many cases better than HgCdTe. For example HgZnTe grown on lattice-matched CdZnTe substrates has fewer defects than corresponding HgCdTe. Both bulk and epi HgZnTe have been grown with defect densities on the order of 10^5 to 10^6 per sq. cm. In addition, HgZnTe is a harder material making it more resistant to processing damage and degradation. Measurements of the Knoop Hardness have been made and show that HgZnTe is about 30 percent harder than HgCdTe. Also, HgZnTe is more resistant to Hg interdiffusion than HgCdTe. Recent annealing measurements show that for equivalent temperatures HgZnTe is about four times more resistant to Hg diffusion than HgCdTe. Electron property measurements of LPE HgZnTe material have yielded mobility values of 4×10^5 cm^2/V-sec and carrier lifetimes of approximately 260 nanosec. Low compositional grading and excellent lateral uniformity have been demonstrated in the LPE material. Recent theoretical developments indicate that the effective mass for electrons in HgZnTe is less than HgCdTe. If this is borne out by experiment then HgZnTe will have less tunneling current than HgCdTe and will make possible longer wavelength PV detectors.

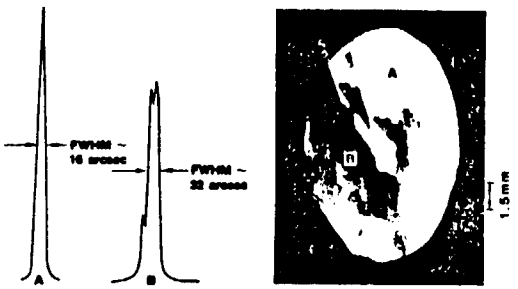
TECHNICAL CONTACT: W.E. Miller, LaRC (804) 865-3761

HgZnTe MATERIAL DEVELOPMENT



HLPE GROWTH TECHNOLOGY

X-RAY ANALYSIS



- $Hg_{0.89}Zn_{0.11}Te$

DISLOCATION COUNT

- ETCH PIT DENSITY

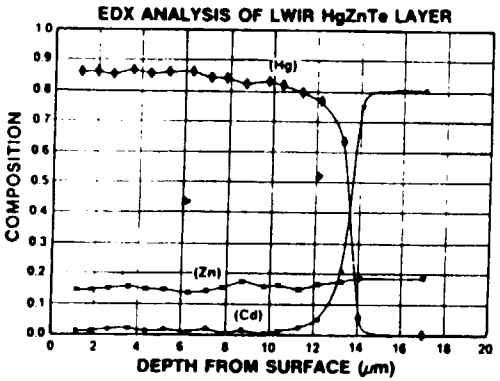
MATERIAL	EPD
$Hg_{0.89}Zn_{0.11}Te$	$1 \times 10^6\ cm^{-2}$
$Hg_{0.86}Zn_{0.14}Te$	$3 \times 10^6\ cm^{-2}$

- TEM
  - DISLOCATION DENSITY = $5 \times 10^5 - 5 \times 10^6\ cm^{-2}$
  - LOW PRECIPITATE DENSITY
  - ZM AND SSR

CRYSTAL QUALITY

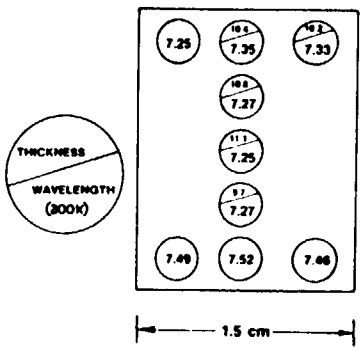
ORIGINAL PAGE IS OF POOR QUALITY

VERTICAL UNIFORMITY COMPOSITION



- $\bar{x} = 0.15$ (LWIR AT 77K)
- $\Delta x / \bar{x} = 0.001$

LATERAL UNIFORMITY CUT-OFF WAVELENGTH



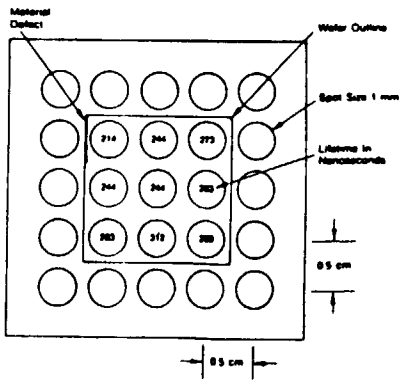
- $\bar{\lambda}_{co} = 7.35\ \mu m$ ($\sigma = 0.1$) AT 300K

MOBILITY

COMPOSITION x-VALUE	AS-GROWN 460°C	ANNEALED 250°C
0.15	$p = 8 \times 10^{17}\ cm^{-3}$ $\mu = 140\ cm^2/V\text{-}sec$	$n = 4 \times 10^{14}\ cm^{-3}$ $\mu = 2 \times 10^4\ cm^2/V\text{-}sec$
0.11	$p = 2 \times 10^{17}\ cm^{-3}$ $\mu = 640\ cm^2/V\text{-}sec$	$n = 2 \times 10^{15}\ cm^{-3}$ $\mu = 4 \times 10^5\ cm^2/V\text{-}sec$

- HALL (VAN DER PAUW AT 77K)

LIFETIME



- OMA AT 85K
- $\bar{\tau} = 262$ ns

COMPOSITIONAL GRADING

MEASURED ELECTRICAL PROPERTIES

Long Wavelength IR Heterodyne Development

The objective of this program is to develop advanced components for far infrared (15-200 μm) heterodyne spectrometers for use in high resolution studies of electromagnetic radiation from astrophysical, planetary, solar and Earth atmospheric sources. High efficiency photomixers, laser local oscillators and a 30 μm radiometer system will be developed. Components will be evaluated and optimized (using miniaturization, integration and ruggedization techniques) with the intended final goal of space flight qualification and eventual use in airplane (KAO, SOFIA) and space-borne systems (Shuttle, Space Station, LDR).

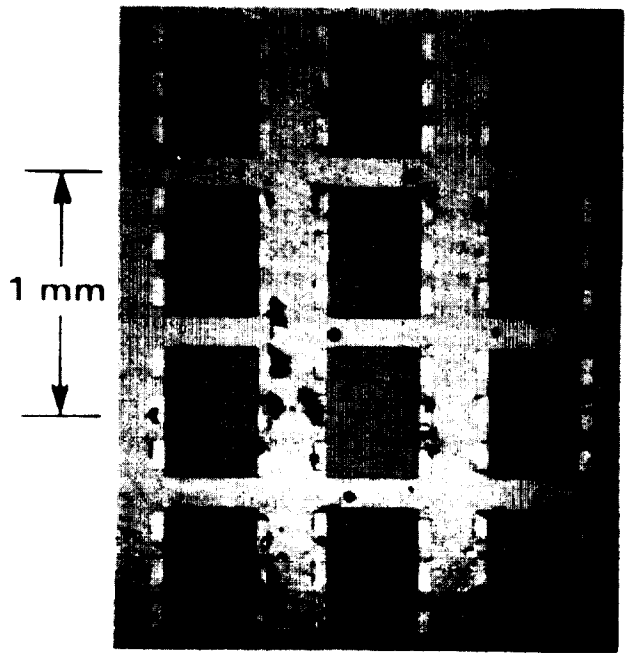
PHOTOMIXERS: HgCdTe photodiode (PD) mixers operating at 28 μm with heterodyne quantum efficiencies ~2% over 500 MHz bandwidths have been developed. Interdigitated-electrode photoconductive (IDEPC) HgCdTe mixers with projected heterodyne quantum efficiencies comparable to photodiodes at 28 μm and 20 times better than GaAs Schottky diodes at 200 μm are being developed. In FY87 first IDEPC mixers were fabricated and evaluated at 10 μm. NEP less than the theoretical value of 2 $h\nu$ for photoconductors was observed. This was due to carrier "sweep out" effects possible with the IDE thin structure design, which eliminates recombination noise in the photoconductor. First, 28 μm mixer arrays were fabricated and tested for wavelength response (> 30 μm). Heterodyne tests are in progress. The design of a 118 μm IDEPC mixer was completed and fabrication will begin in FY88. A new liquid phase epitaxy technique for growing epitaxial layers of HgCdTe was developed (MIT/Lincoln). This technique will provide better material, automatic passivation (CdTe) and non-destructive layer characterization leading to improved HgCdTe photomixers.

LOCAL OSCILLATORS: Mesa stripe PbSnSe diode lasers operating near 30 μm have been developed. Optimization of power output and mode structure and reduction of laser noise has been achieved by reflection coating laser end facets. Some additional optimization was also achieved with antireflection coating the front surface. Double heterostructure stripe geometry lasers, fabricated using liquid phase epitaxy (LPE) methods, are being developed for 30 μm. In FY87 good quality lattice matched double heterostructure 30 μm PbSnSeTe material using the LPE growth technique for diode lasers was developed. First lasers using this material and technique were fabricated and device characterization is in progress.

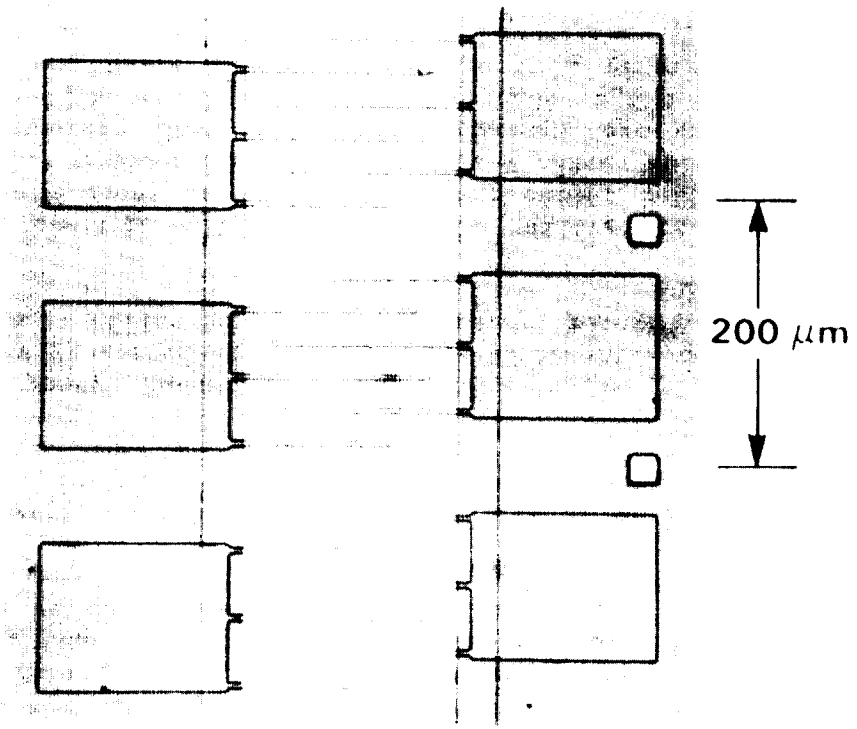
SYSTEM: The improvement of the 30 μm heterodyne radiometer test bed was completed. Completed optical tests indicate an expected three-fold increase in heterodyne efficiency.

TECHNICAL CONTACT: Dr. Theodor Kostiuk, GSFC (301) 286-8431

ARRAY OF INTERDIGITATED-ELECTRODE 28-μm HgCdTe PHOTOMIXERS



FRONT SIDE
(3 × 12 Array)



BACK SIDE
(5X Magnification)

Quantum Well Local Oscillator Sources

The research objective is to develop space qualifiable, solid state sources for use as the local oscillator in submillimeter heterodyne radiometers employing mixers such as superconductor-insulator-superconductor (SIS) junctions.

Heterodyne radiometers are employed in remote sensing applications that require high sensitivity and resolving power such as spectroscopic observations of the earth's atmosphere, planetary atmospheres, and the interstellar medium. The important fundamental rotational and vibrational transitions of the more abundant molecules, including OH, HD, H_3+, and HCl, occur at submillimeter wavelengths. From these observations kinematics of the regions observed can be determined along with the specie's densities, temperatures, and abundances.

A solid state fundamental oscillator employing the negative resistance characteristics of double barrier quantum well devices is being developed to cover the frequency range from 300 to 700 GHz. Harmonic generation using these same devices will provide a source from 700 to 1500 GHz.

Several major advances have occurred during the last year. Fundamental oscillation frequency increased from 60 GHz to 200 GHz. This is the highest frequency generated in a solid state fundamental oscillator to date. 400 μW at 200 GHz generated in a tripler with 1% efficiency. This preliminary result is already competitive with existing technology.

The current-voltage characteristic of double barrier quantum well devices can be tailored to optimize harmonic generation. The negative resistance of the device can amplify harmonic output resulting in higher efficiency than possible with devices that exhibit monotonically increasing I-V curves such as GaAs varactor diodes. Since the I-V curve is anti-symmetric only odd order harmonics are generated, simplifying circuit design. For a sinusoidal pump waveform whose amplitude corresponds to the valley of the I-V curve, third harmonic generation is optimized, while larger amplitudes will generate fifth harmonic output.

The role of parasitics in limiting multiplier performance is much less stringent than in oscillators. They degrade the multiplier performance but do not set a maximum operating frequency. Therefore a quantum well device with a given set of parasitics can be used as multiplier at about twice the frequency it can be used as an oscillator.

A quantum well device with an oscillator f_{max}=280 GHz generated 100 μW output power at 60 GHz and 6 μW at 200 GHz. The same device was mounted in tripler mount and generated 400 μW output power at 200 GHz when pumped with 40 μW at 67 GHz. This implies that quantum well devices in one mode or the other will be able to generate LO power throughout the submillimeter range.

TECHNICAL CONTACT: Dr. Margaret Frerking, JPL (818) 354-4902

JPL

SUBMILLIMETER LOCAL OSCILLATOR SOURCE QUANTUM WELL SOURCES

OAST

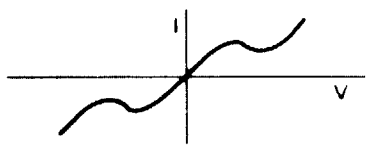
LOCAL OSCILLATOR SOURCES FOR HETERODYNE RECEIVER
FREQUENCY RANGE 300 - 1500 GHz

- 300 - 700 GHz FUNDAMENTAL OSCILLATOR MODE
- 700 - 1500 GHz MULTIPLIER MODE

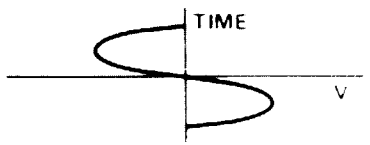
- FUNDAMENTAL OSCILLATOR
  6 μW POWER AT 200 GHz - HIGHEST FREQUENCY FUNDAMENTAL SOLID STATE OSCILLATOR
- MULTIPLIER
  400 μW POWER AT 200 GHz TRIPLED FROM 67 GHz - INITIAL RESULTS ALREADY COMPETITIVE WITH EXISTING TECHNOLOGY

PRINCIPLE OF MULTIPLIER OPERATION

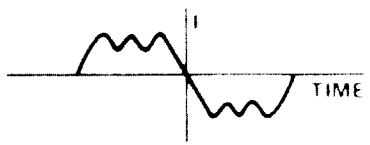
TAILORED I-V CHARACTERISTIC



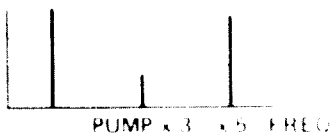
PUMP VOLTAGE WAVEFORM



RESULTANT CURRENT WAVEFORM



CURRENT FREQUENCY COMPONENTS



PUMP x 3 x 5 FREQ

Orifice Pulse Tube Refrigerator

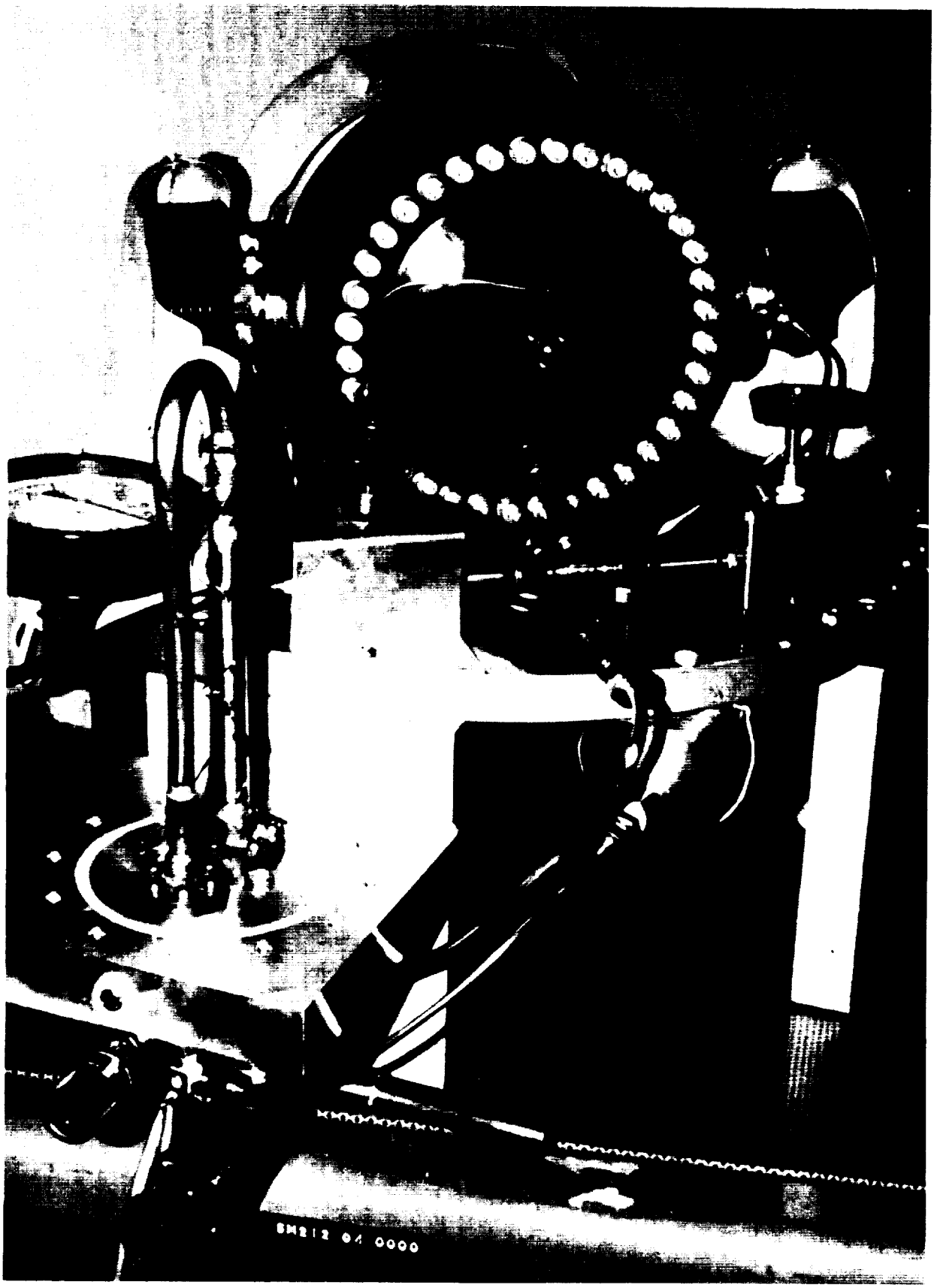
Orifice pulse tube refrigerators are a new type of cooler that have several important advantages over existing coolers (i.e.; Stirling, Gifford-McMahon, Vuilleumier, and Joule-Thomson). The pulse tube has no cold moving parts. Thus it avoids the cold seal and bearing problems of Stirling, G-M, and VM machines, increasing the potential reliability. The only moving part is a room temperature compressor similar to those used in stirling coolers. This compressor has a low pressure ratio, which avoids the problems of high compression ratios found in Joule-Thomson coolers. The orifice in these coolers is relatively large and is in the warm part of the system. Thus it is not subject to blockage by contamination the way the small orifices in Joule-Thomson coolers are.

The orifice pulse tube refrigerator operates on a modified Stirling cycle. The gas is alternately pressurized and depressurized by a low-pressure-ratio compressor. The gas then flows through a regenerator to the pulse tube. This tube has heat exchangers at both ends and an orifice at the far (warm) end. Part of the gas flow goes through the orifice to a ballast volume. The orifice/ballast volume shifts the phase between the volumetric and pressure cycles in the pulse tube. It is this phase shift that causes the cooling. (In Stirling, G-M, and VM coolers this phase shift is provided by a mechanical displacer.) The compressor and regenerator are similar to those used in Stirling, G-M, and VM coolers. The pulse tubes may be staged from a common compressor to reach lower temperatures.

A single-stage cooler has been built in collaboration with the National Bureau of Standards at Boulder. This unit has not been completely optimized yet. Rather it has been used to explore the characteristics of this type of cooler. Despite this, the single-stage device was able to reach 60 kelvin, produce 12 watts of cooling at 80 kelvin, and have an expander efficiency comparable to that of Gifford-McMahon coolers. A photo of the breadboarded cooler is shown in the accompanying chart. Also shown is the efficiency of the expander of our single-stage cooler compared to the theoretical efficiency for expansion engine coolers (Stirling, etc.) and for Joule-Thomson coolers. From this can be seen that the efficiency of the orifice pulse tube is very competitive. The low temperature efficiency should improve for multistage coolers.

TECHNICAL CONTACT: Peter Kittel, ARC (415) 694-4297

ORIFICE PULSE TUBE REFRIGERATOR



Tunnel Junction Mixer Program

The overall objective of this program is to develop all refractory, Superconductor-Insulator-Superconductor (SIS) tunnel junctions for use as ultra-sensitive, low noise mixer elements for millimeter and submillimeter wave heterodyne receivers.

The technical approach involves the deposition of superconductor, niobium nitride (NbN) with T_c~17K by d.c. reactive magnetron sputtering, and fabrication and characterization of NbN/MgO/NbN tunnel junctions. The insulator, MgO is deposited either by rf magnetron sputtering or by E-beam evaporation. The challenging requirements for the device fabrication include the deposition of 5-10 Å of pinhole free insulating barrier and ultra clean interfaces between MgO and NbN. The devices have to have large sum superconducting gap, small subgap leakage current sharp current onset at the sumgap, small RC product, and mechanical, chemical as well as thermal stability. The devices for submillimeter wave application would have to be less than 1 μm^2 in area and would require the use of Electron Beam Lithography.

SIS tunnel junctions have been fabricated from refractory superconductor (superconducting transition temperature, T_c~17K) Niobium nitride (NbN) and the refractory insulator Magnesium oxide (MgO). The NbN/MgO/NbN, SIS thin film structure was deposited entirely in-situ in a high vacuum system using dc reactive magnetron sputtering for the NbN layers and electron beam evaporation for the ultrathin (~10-20 Å) MgO insulator layer. Small area ($7x7\mu m^2$) devices were fabricated and tested by measuring their current-voltage (I-V) characteristics. The devices had I-V curves characteristic of SIS Josephson junctions with well defined superconducting energy gap, zero voltage pair tunneling current, and reasonably sharp onset of normal tunneling. The nonlinear nature of these devices is the key feature necessary for their use as mixer elements in heterodyne receivers. The future plans include fabrication of smaller area NbN/MgO/NbN tunnel junctions while retaining the large sumgap, low subgap leakage current and large current density for operation of submillimeter wave frequencies.

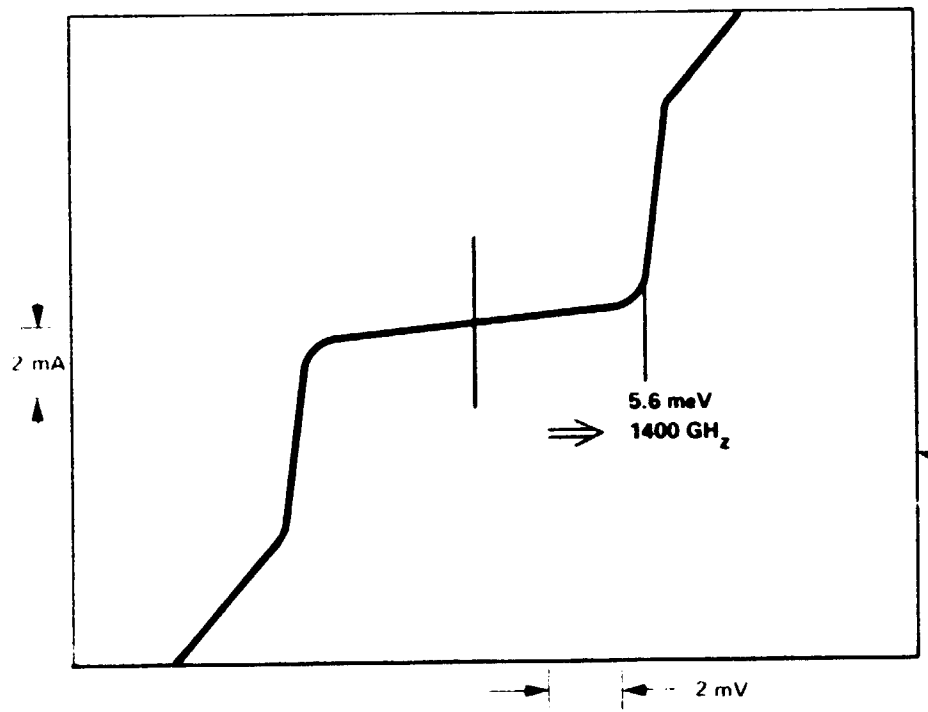
Submillimeter spectral region, spanning the wavelength interval from 1 mm to 100 microns, includes the spectral lines of large numbers of atomic and molecular species of importance to astrophyscics, planetary science, and terrestrial upper atmosphere research. Currently, detector technology in the submillimeter wave region is underdeveloped. The most promising detectors for this region are heterodyne receivers based on superconductor-insulator-superconductor (SIS) quasiparticle mixers. SIS tunnel junctions fabricated from refractory, high superconducting transition temperature (T_c) superconductors are necessary for the development of practical millimeter and submillimeter wave heterodyne receivers. These submillimeter wave heterodyne receivers are needed for several NASA missions such as Explorer, Large Deployable Reflector (LDR), and Earth Observing System (EOS).

TECHNICAL CONTACTS: Satish Khanna, JPL (818) 354-4489
Henry LeDuc, JPL (818) 354-2209

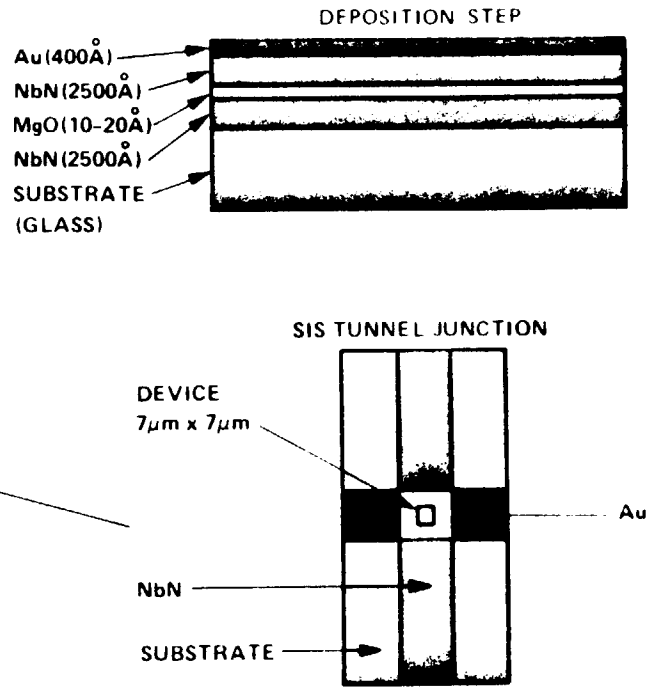
SUPERCONDUCTOR-INSULATOR-SUPERCONDUCTOR TUNNEL JUNCTION MIXER PROGRAM

JPL

GOAL: TO DEVELOP SUPERCONDUCTOR-INSULATOR-SUPERCONDUCTOR TUNNEL JUNCTION MIXER FOR SUBMILLIMETER HETERODYNE RECEIVER



CURRENT-VOLTAGE CHARACTERISTICS OF NbN/MgO/NbN TUNNEL JUNCTION



SCHEMATIC DIAGRAM OF SIS TUNNEL JUNCTION FABRICATION

Solid-State Photomultiplier for Infrared Astronomy

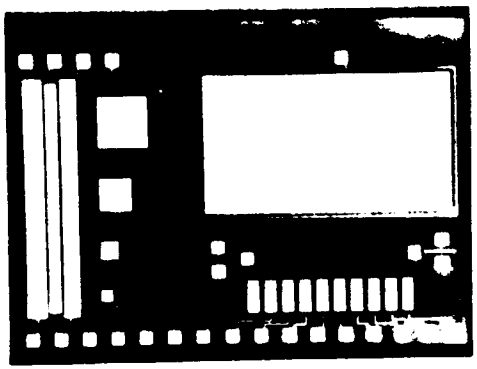
As was noted in the "Richards Report" (NASA TM 78598, June 1979), which recommended development priorities for infrared astronomical applications, an ideal direct detector is one which "can detect the arrival of a single signal photon" in an intrinsically "nearly noiseless" fashion. In 1979 infrared direct detectors sensitive beyond about 1.5 μm were "at least 2 or 3 orders of magnitude short of counting single photons." A recent discovery at the Rockwell International Science Center has changed this situation dramatically. The solid-state photomultiplier (SSPM), produced in arsenic-doped silicon (Si:As), has been shown to count individual photons, with a long-wavelength cutoff of about 28 μm. This device is particularly well suited to low-background applications because of its limited count-rate capacity. Because of the pulse nature of the device output, on-chip digital electronics are applicable, which promises to circumvent the pickup problems associated with low-level analog electronics. A research contract has been set up with Rockwell to investigate in detail the applicability of the SSPM to astronomical applications such as the Space Infrared Telescope Facility (SIRTF), and to identify and investigate the factors which would limit its performance when operated in this environment.

Recent experimental data show that quantum efficiencies over 30% (comparable to that of state-of-the-art extrinsic silicon bulk photoconductors) and a minimum dark count rate of 18 counts/s have been achieved with the SSPM. The performance of the device is strongly temperature-dependent in the 5.7 - 9 kelvin range. Data are being taken over a range of bias, temperature, and background conditions to build an experimental data base. In parallel, a detailed modelling activity is underway. Using a remote connection to the ARC Cray X-MP, Rockwell researchers are investigating the avalanche gain mechanism in the SSPM, and developing models of device noise. An experimental effort at ARC will begin shortly in which the exact output pulse shape will be measured. Development progress has been very good on this novel device, which promises to improve the sensitivity of space-based measurements and to allow new scientific investigations (e.g., high-speed photometry) to be considered.

TECHNICAL CONTACT: Craig R. McCreight, ARC (415) 694-6549

SOLID-STATE PHOTOMULTIPLIER FOR IR ASTRONOMY

FIRST DEMONSTRATION OF FAR-IR PHOTON COUNTING

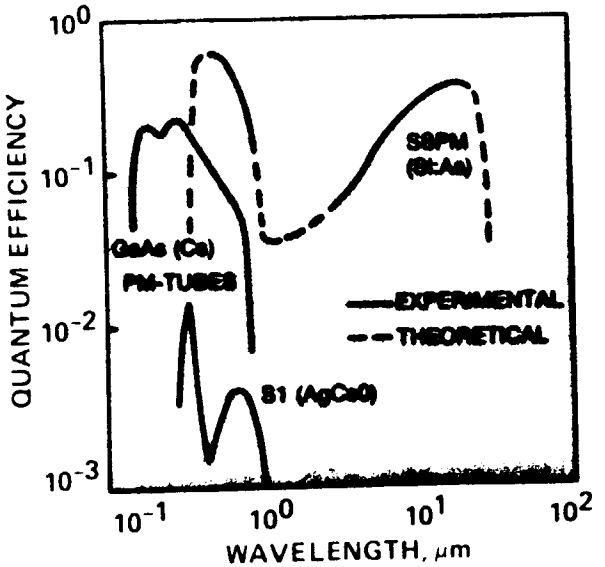


10 - ELEMENT Si:As ARRAY

PULSE RESPONSE TO CHOPPED ILLUMINATION

NOVEL CHARACTERISTICS FOR LOW-BACKGROUND ASTRONOMY

- PULSE OUTPUT
- HIGH INTERNAL GAIN (~ 50,000)
- FAST RESPONSE
- INHERENT RADIATION HARDNESS
- LOW DARK COUNT RATE (~ 20/s)
- GOOD QUANTUM EFFICIENCY (~ 30%)



BROAD SPECTRAL COVERAGE

OAST-Sponsored Research

Ames Research Center

Imaging X-Ray Spectrometer

The objectives of this program are to produce an array of X-ray detectors with high quantum efficiency, with energy resolution less than 250 electron volts in the 1 to 30 Kev range and to preclude charge splitting between pixels. This requires low acoustic noise and low capacitance at the detector. Hexagonally shaped 19 pixel arrays that match the circular view of the telescopes on BBXRT and AXAF candidate instrument re-flights have been fabricated using "deep diode" technology. The consistency of the pixels has been poor. Much of this is attributed to the thermalmigration processing step, so a new configuration using drift detector technology is being pursued that can be configured to meet the detection needs of a wide energy spectrum. Electrical testing procedures appropriate to both the detector technologies have been devised and carried out. Evaluation will continue as these are complex and time-consuming processes.

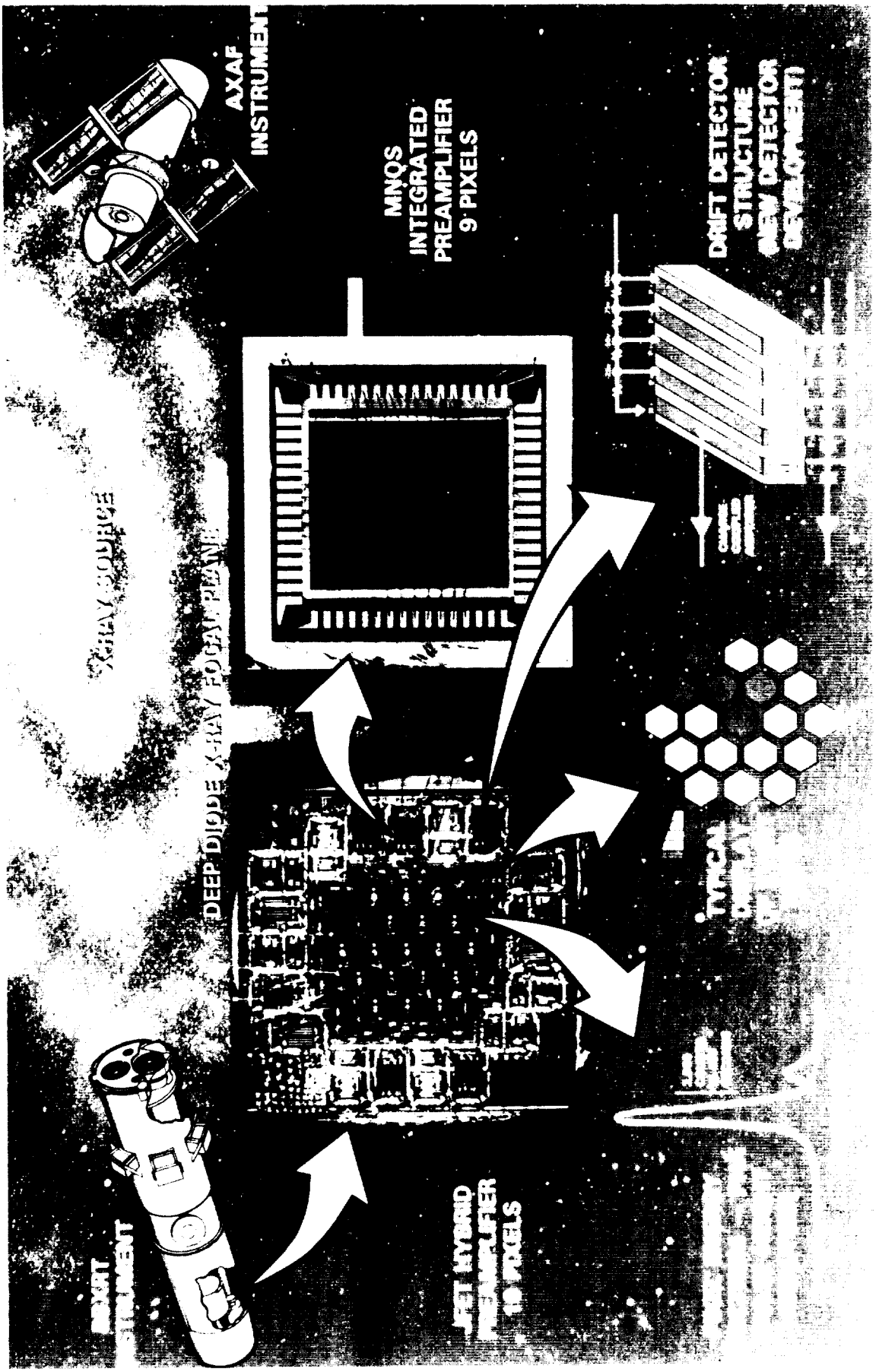
Two focal-planes have been fabricated and comparison will be between JFET and MOS preamplifiers of similar configurations. Cryogenic testing of the focal planes is proceeding. The preamplifiers are very consistent and well integrated on the 77 K focal plane. Improvements in focal plane assembly techniques for many pixels have progressed and 4416 JFETS of the lowest noise yet produced have been received and are ready for testing and assembly. Our circuit simulations using "SPICE" software have been frustrating because our high gain amplifiers and desired feedback impedances simulated causes the software to not "converge" to a solution or "overflow" in matrix solution. Alternative software is being sought.

The Drift detector development will be extended to cosmic rays in future years, requiring different and larger assemblies.

The following picture summarizes our project. A re-flight of BBXRT with this X-ray detector at the 77 k focal plane will image galactic sources. Both hybrid JFET and lower capacitance MOS integrated preamplifiers will be compared in over-all performance and reliability. JFETS require significantly more power to be lowest noise. The present detectors use thermalmigration to drive aluminum posts through the thick wafer, but better consistency is expected by adapting the technology to drift detector structures. The results needed are statistical Pulse Height Analysis (PHA) of the events to define the percentages of each element making up the X-ray population and an image of the intensities making up an image of the source being studied.

TECHNICAL CONTACT: Donald C. Lokerson, GSFC (301) 286-5378

IMAGING X-RAY SPECTROMETER FOR 1 TO 30 KeV



Submillimeter Heterodyne Receiver

The objective of this program is the development of high resolution heterodyne receivers for the submillimeter region (i.e., 100 μm to 1000 μm wavelength). This important spectral range contains many molecular emissions of astrophysical interest which can only be viewed from an airborne or space platform. Facilities in which such a system will be based are the proposed 3-meter airborne observatory, SOFIA, small ambient temperature telescope on a SPARTAN or EURECA carrier, or the large ambient temperature telescope, LDR. To this end the program has concentrated on developing each component of such a receiver system, mainly the LO, the mixer, and the backend processor, for rugged operation in an aircraft or for space operation.

The local oscillator development concentrates on the construction of rugged and compact optically-pumped laser LO's. Although the use of lasers as LO is a proven technology, size, ruggedness, lifetime considerations, and the difficulty of remote operations must be addressed in order to attain feasible space operation. We have identified and will procure in FY88 a RF-excited waveguide CO_2 laser which has the possibility of being space-qualified. The United Technologies Research Center laser is very compact, about 19 in. length, lightweight, about 20 lbs., and operates under 2.5G 3-axis vibration. We will integrate this CO_2 laser to a FIR system for evaluation and operation as a LO system.

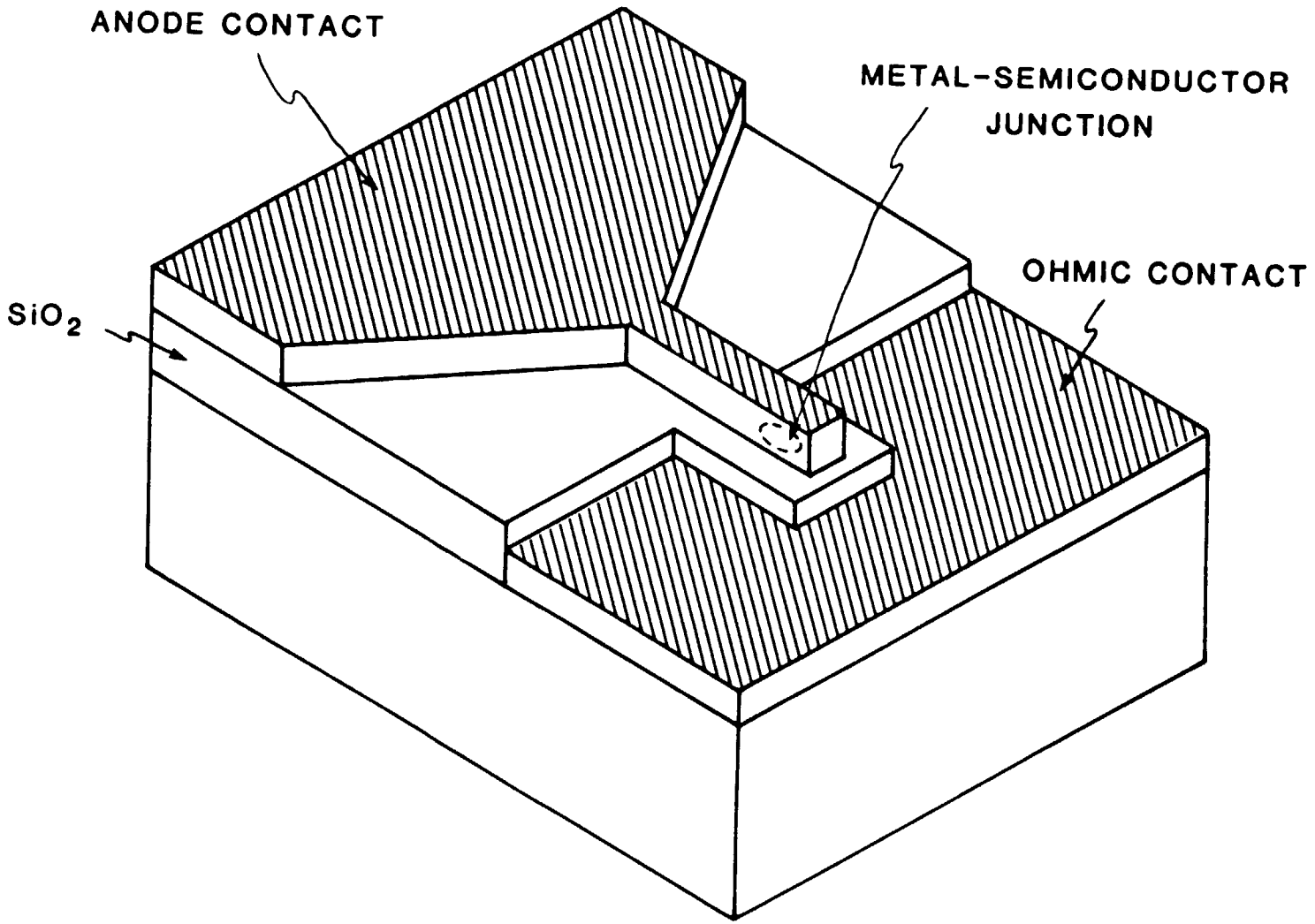
The mixer development is concentrated on the research performed at the University of Virginia (Dr. R. Mattauch) both in improving GaAs Schottky mixer elements for use in a corner-cube configuration and in a new type of planar whiskerless Schottky diodes. The potential of the new planar Schottky diodes is that an imaging array of these devices may be constructed for heterodyne receivers.

In the past OAST has funded development of the third component of the heterodyne receiver, the miniaturized Acousto-Optic Spectrometer (mAOS), which offers a tremendous savings in weight, volume, and power over conventional RF techniques to retrieve the spectral information in heterodyne receivers. A prototype mAOS has been constructed and tested, and integrated with the Kuiper Airborne Observatory (KAO) heterodyne receiver system. However, the prototype unit is far from being considered a space-qualified unit.

We have flown a single engineering flight on the (KAO) at the beginning of FY87. The major portion of the receiver system worked; however, we were not able to obtain any scientific data on this KAO campaign.

TECHNICAL CONTACT: Dr. Gordon Chin, GSFC (301) 286-8649

WHISKERLESS SCHOTTKY BARRIER DIODE



Mid-Infrared Laser Development

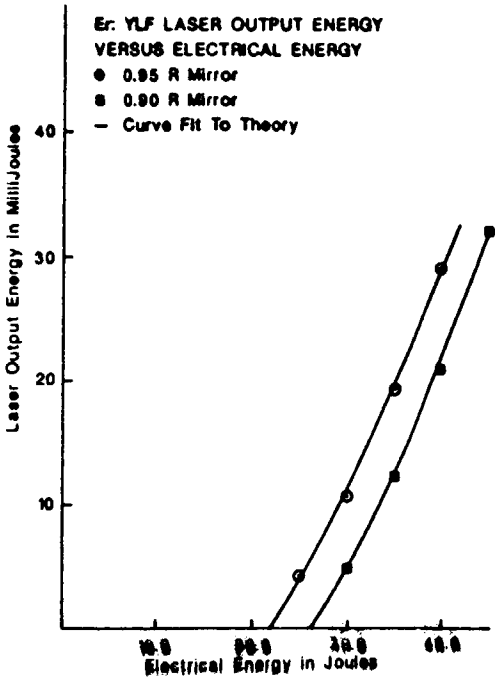
A major active sensing technology goal has been established to develop the capability to interrogate all minor atmospheric constituents with a solid-state laser. Since some of the constituents occur only in trace amounts, it was decided to focus on interrogating the strong fundamental absorption lines in the mid-infrared, rather than the weaker overtone lines in the mid-infrared. To effectively accomplish this with solid-state lasers requires a two-step approach. First is the development of an efficient pump laser in the 1.5 to 2.1 micron region; second is the development of an optical parametric oscillator which will convert the pump radiation to tunable radiation in the mid-infrared region of the spectrum. Two of the candidates for the pump laser are Er:YLF and Ho:YAG. The former has the advantage of being able to operate at room temperature; the latter has the advantage of having a higher potential for efficiency. While both options need to be compared, fabrication and testing of the first was deemed prudent since it did not require cooling. Thus, it could be used for optical parametric oscillator experiments while the Ho:YAG laser was being developed.

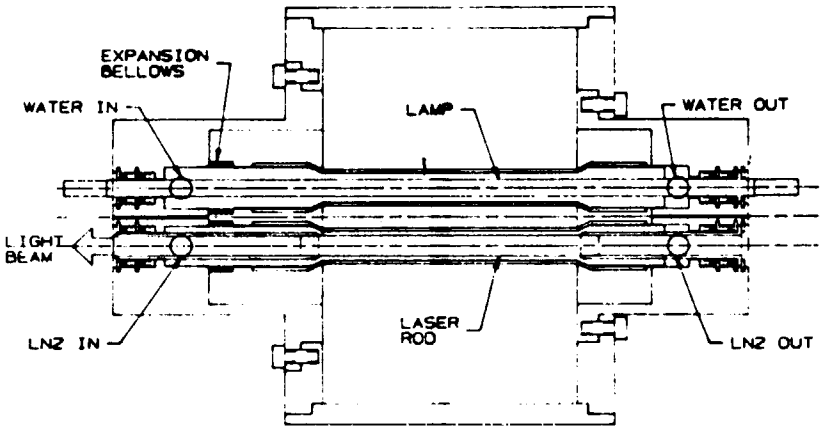
Er:YLF can operate at 1.732 microns and can be pumped either with a flashlamp or with a frequency doubled Nd laser. Flashlamp pumping was tried first, and an entire laser system, including the simmer supply and pulse forming network, has been fabricated. To date, the Er:YLF has produced 35 mJ in normal mode operation. Tests are currently underway to increase the output energy and to implement an electro-optic Q-switch. In the future, laser pumping of this transition is planned.

Ho:YAG development has begun with the design of a laser cavity capable of cooling the laser rod to liquid nitrogen temperatures while maintaining the flashlamp at room temperature. A preliminary design has been produced and is currently undergoing thermal analysis and component testing. Although experiments performed by Langley personnel indicate that liquid nitrogen cooling will not be necessary, a comparative study of the relative efficiency of Ho:YAG as a function of temperature and active atom concentration still must be performed. This study has been initiated, and will be carried out through a cooperative program between Langley and the Air Force. Further cooperation with the Air Force has been agreed upon in a memorandum of understanding through which the Air Force intends to provide the heart of the optical parametric oscillator, the nonlinear crystal.

TECHNICAL CONTACT: Dr. N.P. Barnes, LaRC (804) 865-3761

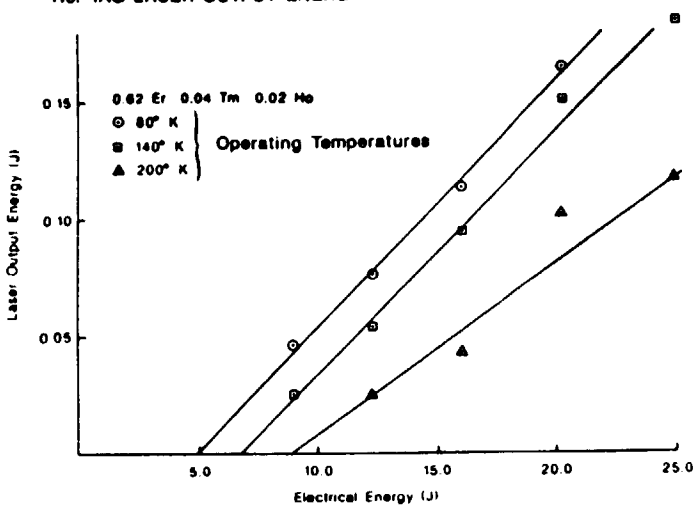
DEVELOPMENT OF LONG WAVELENGTH, EYESAFE LASERS FOR REMOTE SENSING APPLICATIONS



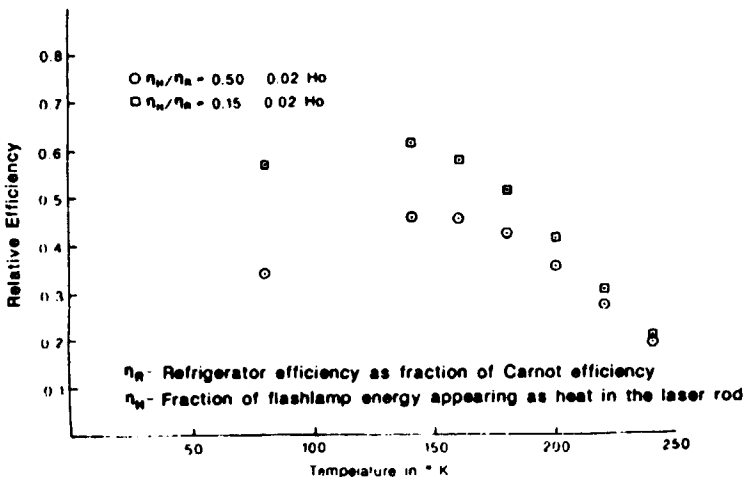


LASER DESIGN CAVITY-001

Ho: YAG LASER OUTPUT ENERGY VERSUS ELECTRICAL ENERGY



RELATIVE TOTAL EFFICIENCY OF Ho: YAG VERSUS TEMPERATURE



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